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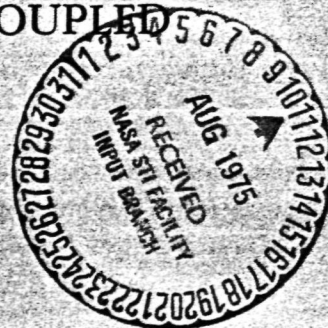
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CANARD CONFIGURATION

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EFFECT OF VERTICAL-TAIL LOCATION ON THE
AERODYNAMIC CHARACTERISTICS AT SUBSONIC SPEEDS OF A
CLOSE-COUPLED CANARD CONFIGURATION

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SUMMARY

A study was conducted to determine the effects of various vertical-tail configurations on the longitudinal and lateral directional-stability characteristics of a general research fighter model utilizing wing-body-canard. The study indicates that the addition of the high canard resulted in an increase in total lift at angles of attack above 4° with a maximum lift coefficient about twice as large as that for the wing-body configuration. For the wing-body (canard off) configuration, the center-line vertical tail indicates positive vertical-tail effectiveness throughout the test angle-of-attack range; however, for this configuration none of the wing-mounted vertical-tail locations tested resulted in a positive directional-stability increment at the higher angles of attack.

For the wing-body-canard configuration several outboard locations of the wing-mounted vertical tails were found. These outboard locations encountered favorable interference from the canard such that their directional-stability contribution increased in the high angle-of-attack range. However, all locations of the wing-mounted vertical tails caused a loss in total lift coefficient with the inboard, forward location indicating the smallest effect. The results also show that the upper segment of these vertical tails provides the largest contribution to directional stability, particularly at the high angles of attack.

The results of the study indicate that by careful selection of tail location a favorable canard interference is encountered. Therefore it would appear that for a configuration with a more representative fuselage a directional stability should be obtained with reasonably sized surfaces.

INTRODUCTION

In the studies presented in references 1 to 8, it was shown that the addition of canard surfaces may provide performance improvements to maneuvering aircraft configurations.

These studies have concentrated almost entirely on the longitudinal aerodynamic characteristics of the configurations over a wide angle-of-attack range. In order to take advantage of the increased maneuvering performance that a canard or any other maneuvering concept may offer, the configuration must exhibit good handling qualities over a wide range of maneuvering conditions. Because of the interest in the longitudinal aerodynamic characteristics, a knowledge of the interference effects of the canard and canard flow fields on the lateral-directional characteristics of a representative configuration at high angle of attack is of increased importance. Therefore, the present paper presents the results of a research program which studied the effects of vertical-tail locations on the aerodynamic characteristics of a close-coupled canard configuration. This study was conducted in the Langley high-speed 7- by 10-foot tunnel at a Mach number of 0.30. The angle-of-attack range of the study varied from -4° to 40° at sideslip angles of 0° and $\pm 5^{\circ}$.

SYMBOLS

The International System of Units, with the U.S. Customary Units presented in parentheses, is used for the physical quantities in this paper. Measurements and calculations were made in the U.S. Customary Units. All data presented in this report are referred to the stability-axis system as indicated in figure 1.

A	aspect ratio, b^2/S (2.50)
b	wing span, 50.8 cm (20 in.)
C_D	drag coefficient, $\frac{\text{Drag}}{qS}$
C_L	lift coefficient, $\frac{\text{Lift}}{qS}$
C_l	rolling-moment coefficient, $\frac{\text{Rolling moment}}{qSb}$
$C_{l\beta}$	rolling moment due to sideslip, $\frac{\partial C_l}{\partial \beta}$, per deg
C_m	pitching-moment coefficient, $\frac{\text{Pitching moment}}{qS\bar{c}}$
C_n	yawing-moment coefficient, $\frac{\text{Yawing moment}}{qSb}$
$C_{n\beta}$	yawing moment due to sideslip, $\frac{\partial C_n}{\partial \beta}$, per deg
C_Y	side-force coefficient, $\frac{\text{Side force}}{qS}$

$C_{Y\beta}$	side force due to sideslip, $\frac{\partial C_Y}{\partial \beta}$, per deg
c	local chord, cm (in.)
\bar{c}	wing mean geometric chord, 23.32 cm (9.18 in.)
$\Delta C_{l\beta,C}$	interference effect of the canard on the effective dihedral parameter $(C_{l\beta,WBCVT} - C_{l\beta,WBVT})$
$\Delta C_{n\beta,C}$	interference effect of the canard on the directional stability $(C_{n\beta,WBCVT} - C_{n\beta,WBVT})$
$\Delta C_{l\beta,VT}$	effect of vertical tail on the effective dihedral parameter $(C_{l\beta,WBCVT} - C_{l\beta,WBC})$
$\Delta C_{n\beta,VT}$	vertical tail effectiveness $(C_{n\beta,WBCVT} - C_{n\beta,WBC})$
M.S.	model station, cm (in.)
q	free-stream dynamic pressure
S	reference area of wing with leading and trailing edges extended to plane of symmetry, 0.1032 m ² (1.1109 ft ²)
S_C	exposed canard area, 0.30S
α	angle of attack, deg
β	angle of sideslip, deg

Subscripts:

B	body
C	canard
fb	forward balance
VT	vertical tail
W	wing

DESCRIPTION OF MODEL

A drawing of the general research model is shown in figure 2. Figure 3 presents a photograph of the model without the vertical tail mounted in the Langley high-speed 7- by 10-foot tunnel. The basic model as illustrated in figure 2(a) consisted of a mid-wing, high-canard combination with the uncambered and untwisted wing having an aspect ratio of 2.5, a taper ratio of 0.20, a wing leading-edge sweep of 44° , and a circular-arc airfoil section with a thickness of 6 percent at the body juncture and 4 percent at the wing tip.

The canard had a leading-edge sweep of 51.7° and an exposed area (S_c) of 30 percent of the reference wing area. It was untwisted and uncambered with a circular-arc airfoil section that varied in thickness ratio from 6 percent at the body juncture to 4 percent at the tip. (See fig. 2(a).) The canard was tested at a location above the wing chord plane as shown in figure 2(a).

A single vertical tail mounted along the fuselage center line (see figs. 2(b) and 4) as well as wing-mounted vertical tails (see figs. 2(c) and 4) were investigated. The center-line tail had a leading-edge sweep of 51.7° and an exposed area of 16 percent of the reference wing area (see fig. 2(b)) with a circular-arc airfoil section that varied from 6 percent at the body juncture to 4 percent at the tip. The wing-mounted vertical tails were located on the upper and lower surfaces of the wing with their total exposed area equal to the area of the single center-line vertical tail. The wing-mounted vertical tails were of constant thickness with beveled trailing edges and rounded leading edges as shown in figure 2(c). Their location was varied longitudinally and spanwise as shown in figure 4.

The moment reference point was taken to be at fuselage station 59.16 cm (23.29 in.) as shown in figure 2(a).

APPARATUS, TESTS, AND CORRECTIONS

This investigation was made in the Langley 7- by 10-foot high-speed (atmospheric) wind tunnel. Forces and moments were measured by two internally mounted, six-component strain-gage balances. The forward balance was rigidly mounted to the aft section of the model and measured the loads on the forward segment of the fuselage (shaded area of fig. 2(a)); this balance is referred to as the forward balance. There was a small unsealed gap of 0.229 cm (0.090 in.) between the segments of the fuselage in order to prevent fouling of the forward balance. (See fig. 2.) The second balance, which was located in the aft segment of the model, measured the total load on the model; this balance is referred to as the main balance.

The test was made at a Mach number of about 0.3 which corresponded to a Reynolds number of 1.53×10^6 based on the mean geometric chord. The angle-of-attack range was -4° to 40° at sideslip angles of 0° and $\pm 5^\circ$. The angles of attack and angle of sideslip have been corrected for the effects of balance and sting bending under aerodynamic loads. The drag measurements of the main balance were adjusted to a condition of free-stream static pressure acting on the base of the model. Transition strips 0.08 cm (0.031 in.) in width and No. 90 carborandum grains were placed 1.14 cm (0.45 in.) streamwise from the leading edge of the wing, vertical tails, and canard as well as 3.28 cm (1.29 in.) behind the nose of the fuselage as in reference 9.

PRESENTATION OF RESULTS

The longitudinal characteristics are presented in figures 5 to 9 and the lateral-directional characteristics in figures 10 to 14. The following list of figures is presented as an aid in locating the results of a particular configuration:

	Figure
Longitudinal aerodynamic characteristics of wing-body-canard configuration with center-line vertical tail or wing-mounted vertical tail at locations 1, 2, and 3	5
Longitudinal aerodynamic characteristics of the wing-body configuration with center-line vertical tail or wing-mounted vertical tails at locations 1, 2, and 3	6
Longitudinal aerodynamic characteristics of wing-body-canard configuration with center-line vertical tail or wing-mounted vertical tails at locations 4 and 5	7
Longitudinal aerodynamic characteristics of the wing-body configuration with center-line vertical tail or wing-mounted vertical tails at locations 4 and 5	8
Comparison of the longitudinal aerodynamic characteristics of the wing-body-canard configuration with center-line vertical tail or wing-mounted vertical tails with lower surface vertical tail on and off at location 3	9
Lateral-directional derivatives for the wing-body-canard configuration with center-line vertical tail or wing-mounted vertical tails at locations 1, 2, and 3	10
Lateral-directional derivatives for the wing-body-canard configuration with center-line vertical tail or wing-mounted vertical tails at locations 4 and 5	11
Lateral-directional derivatives for the wing-body configuration with center-line vertical tail or wing-mounted vertical tails at locations 1, 2, and 3	12

	Figure
Lateral-directional derivatives for the wing-body configuration with center-line vertical tail or wing-mounted vertical tails at locations 4 and 5	13
Comparison of the lateral-directional derivatives of the wing-body-canard configuration with center-line vertical tail or wing-mounted vertical tails with the lower surface vertical tail on and off at location 3	14
Effect of canard on the longitudinal aerodynamic characteristics of the basic model with vertical tail off	15
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Vertical-tail effectiveness for the various vertical-tail configurations	17
Effect of the various vertical-tail configurations on the effective dihedral parameter	18
Vertical-tail effectiveness for wing-mounted vertical tails at position 3 for the wing-body-canard configuration	19

DISCUSSION

Longitudinal Characteristics

Figures 5 to 9 present the basic longitudinal aerodynamic characteristics for the wing-body and wing-body-canard configurations. The addition of the high canard to the wing-body configuration (data presented in figs. 5 and 6 and compared in fig. 15) resulted in an increase in total lift at angles of attack above about 4° with a total maximum lift nearly twice as large as that produced by the wing-body configuration. However, the wing lift (see fig. 15(c)) shows a loss at low and moderate angles of attack caused by the canard downwash, with an increase in maximum wing lift of about 28 percent. These results can be attributed to mutual beneficial interference effects of the canard on the wing and of the wing on the canard and are discussed in more detail in references 8 and 10.

The variation in the pitching-moment coefficient with the lift coefficient (see fig. 15(a)) was linear up to the stall, above which the canard configurations initiated a pitchup while the wing-body configuration showed a stable break. The center-of-gravity location was chosen to obtain a stable wing-body configuration; therefore, the wing-body-canard configuration is unstable because the lift generated by the canard surface is acting ahead of the center of gravity. As discussed in reference 10 and shown in the data herein, the wing-body-canard configuration exhibited a significantly lower drag due to lift than did the wing-body configuration. (See fig. 15(b).)

When the single vertical tail is added at the body center line (see fig. 2), the longitudinal characteristics of either the wing-body or the wing-body-canard configurations, as would be expected, are generally unaffected. (See figs. 5 and 6.)

Placing the twin vertical tails on the wings of the wing-body-canard configuration in positions 1, 2, or 3, as shown in figure 4, caused a significant loss in lift at the higher angles of attack, an increase in drag due to lift, and a pitchup tendency which occurred at a lower lift coefficient than with tails off. (See fig. 5.) The loss in lift is probably caused by an interaction of the wing-canard flow field with the wing-mounted vertical tails resulting in both a wing flow separation and a loss in vortex lift on the wing panel. This result is evidenced by the absence of large effects of the vertical tails on the wing-body characteristics. (See fig. 6.) As the vertical tails are moved inboard (see fig. 4 and the data of fig. 5) from the wing tips (position 1) the lift decreased and the drag increased significantly, especially in the moderate angle-of-attack range (16° to 24°). It should be noted that the loss in maximum lift coefficient caused by the addition of the wing-mounted vertical tails is not just associated with the wing, but the disturbances are felt forward on the canard such that about 25 percent of the lift loss is on the canard surface. (See fig. 5(b).)

Moving the vertical tails forward on the wing to positions 4 and 5 (see figs. 7 and 8) recovered some of the lift loss previously shown for the rear positions of the vertical tails (positions 1, 2, and 3). For the vertical tails in position 4, nearly all of the lift loss is recovered. The vertical tails in this position appear to have minimum interference with the beneficial effects attributed to the leading-edge vortex.

Figure 9 shows the effect of removing the lower surface vertical tails for the vertical tails located at position 3 on the wing-body-canard configuration. The data indicate that removal of the lower surface vertical tails has no effect on the longitudinal aerodynamic characteristics up to a lift coefficient of about 1.3. Above 1.3 a slight increase in maximum lift is noted when compared to the complete configuration with the upper and lower wing-mounted vertical tails. It would appear that the upper surface vertical tails were the major contributor to the lift loss.

Lateral-Directional Stability Characteristics

The effects of the various vertical-tail configurations on the lateral-directional derivatives are presented in figures 10 to 14 as a function of the angle of attack. The following discussion is based on incremental effects, since the fuselage of the model tested does not represent the fuselage that would be utilized on an actual aircraft. The total effects of the canard on the directional stability and the effective dihedral parameter ($\Delta C_{n\beta,C}$ and $\Delta C_{l\beta,C}$, respectively) as a function of angle of attack are presented in figure 16. The addition of the canard caused a large negative directional-stability increment at angles of attack above 20° . This negative increment associated with the addition of the canard is present regardless of the vertical-tail configuration and appears to be primarily the result of a change in sidewash on the aft fuselage. The addition of the center-line vertical tail resulted in an even greater adverse effect on the directional-stability increment

associated with the canard as well as a more negative effective dihedral parameter at moderate and high angles of attack. This further indicates that the sidewash is adverse in the region of the vertical tail. A slight destabilizing incremental contribution is noted from the forward fuselage section of the model upon the addition of the canard. (See figs. 10(b) and 12(b).)

The results for the wing-mounted vertical tails at locations 1, 2, and 3 are also presented in figure 16. The large unfavorable effect of adding the canard to the configuration with the vertical tails off is significantly reduced for the configuration with the twin vertical tails. This reduction would indicate that the twin tails may be located in a region of favorable sidewash at the higher angle of attack. The data also show that as the vertical tails are moved inboard along the same longitudinal line (same tail length) little or no effect is noticed up to an 18° angle of attack, above which angle inboard movement from positions 1 to 2 resulted in a decrease in the unfavorable canard directional-stability increment and a more negative effective dihedral-parameter increment. However, inboard movement from positions 2 to 3 resulted in only a slight change in the directional-stability increment with essentially no change in the effective dihedral-parameter increment.

When the vertical tails are located at position 4, the results show a slight, favorable stability increment up to about a 19° angle of attack and large unfavorable stability effects at the higher angles of attack. In the range of angles of attack between 20° and 26° , the unfavorable effect appears larger than for the tail-off configuration, indicating an unfavorable sidewash on the twin vertical tails. At position 5 the data indicate that the twin tails are in an unfavorable sidewash field up to angles of attack of about 30° . (Note the larger unfavorable increment for the twin tails than for the tail job.) Thus, for the wing-mounted vertical-tail locations investigated, a location inboard of the wing tip and outboard of the canard tip encounters favorable canard interference, thereby reducing the overall adverse canard effect.

The vertical-tail effectiveness parameter and the effect of the vertical-tail configuration on the effective dihedral parameter, respectively, as a function of angle of attack are presented in figures 17 and 18. For the canard-off configuration (right side of figure), the center-line vertical tail shows positive effectiveness over the entire test angle-of-attack range. The data for the wing-body configuration with the vertical tails off presented in figure 12(a) indicate a favorable interference effect at high angles of attack resulting in the configuration exhibiting positive stability at angles above 23° . This effect is the result of a favorable sidewash on the aft fuselage of the configuration. This favorable sidewash was undoubtedly carried over to the configuration with the center-line vertical tail as evidenced by the positive increment in stability above a 24° angle of attack. When the vertical tails are wing mounted (canard off), the vertical-tail effectiveness is at best neutral at angles of attack above 23° , indicating that the wing-mounted vertical tails are located in an unfavorable sidewash field.

The addition of the canard to the configuration with the center-line vertical tail resulted in a loss in tail effectiveness such that, at an angle of attack above 24° , the contribution of the vertical tail to stability was destabilizing. This effect is probably caused by the canard flow field altering the induced sidewash in the area of the vertical tail. For the wing-mounted vertical tails 1, 2, and 3 (canard on), the effectiveness is positive and essentially constant up to 18° angle of attack; above this angle the effectiveness increases with increasing angles of attack. At positions 2 and 3, because of a favorable canard interference, a positive effectiveness over the entire angle-of-attack range results. The data for the configuration utilizing wing-body-canard with wing-mounted vertical tails at positions 4 and 5 indicate that at position 4 the vertical tails show positive effectiveness with an increasing angle of attack; at position 5 the effectiveness is positive up to about 23° . The data of figure 18 indicate little or no effect of the vertical-tail configurations on the effective dihedral parameter. However, the addition of the canard in general caused a slightly more positive effective dihedral parameter for all vertical-tail configurations at high angles of attack.

The vertical-tail effectiveness for the wing-mounted vertical tails at position 3 for upper and lower surface-mounted and for upper surface only is shown in figure 19. The data indicate that at low to moderate angles of attack the upper surface vertical tails provide about half of the directional-stability increment, while at angles of attack above 23° they provide about two-thirds of this total increment.

CONCLUSIONS

A study to determine the effects of various vertical-tail configurations on the longitudinal and lateral stability characteristics of a general research fighter model utilizing wing-body-canard indicated the following results:

1. The addition of the high canard to the wing body resulted in an increase in total lift at angles of attack above about 4° with a maximum lift coefficient about twice as large as that produced by the wing-body configuration.

2. For the wing body (canard off), the center-line vertical tail indicated positive vertical-tail effectiveness throughout the test angle-of-attack range.

3. For the wing-body configuration none of the wing-mounted vertical-tail locations tested resulted in a positive directional-stability increment at the higher angles of attack.

4. The addition of the canard to the wing-body center-line vertical-tail configuration produced a large negative increment in directional stability at the higher angles of attack.

5. For the wing-body-canard configuration several outboard locations of the wing-mounted vertical tails were found to have favorable interference from the canard such that their directional-stability configurations increased in the higher angle-of-attack range.

However, all locations of the wing-mounted vertical tail caused a loss in total lift coefficient. The inboard, forward location indicated the smallest effect.

6. The results showed that the upper segment of the vertical tail provided the largest contribution to directional stability, particularly at the higher angles of attack.

7. The results of the study indicated that by careful selection of tail location a favorable canard interference was encountered. Therefore, it would appear that for a configuration with a more representative fuselage, a directional stability should be obtained with reasonably sized surfaces.

Langley Research Center,
National Aeronautics and Space Administration,
Hampton, Va., May 20, 1975.

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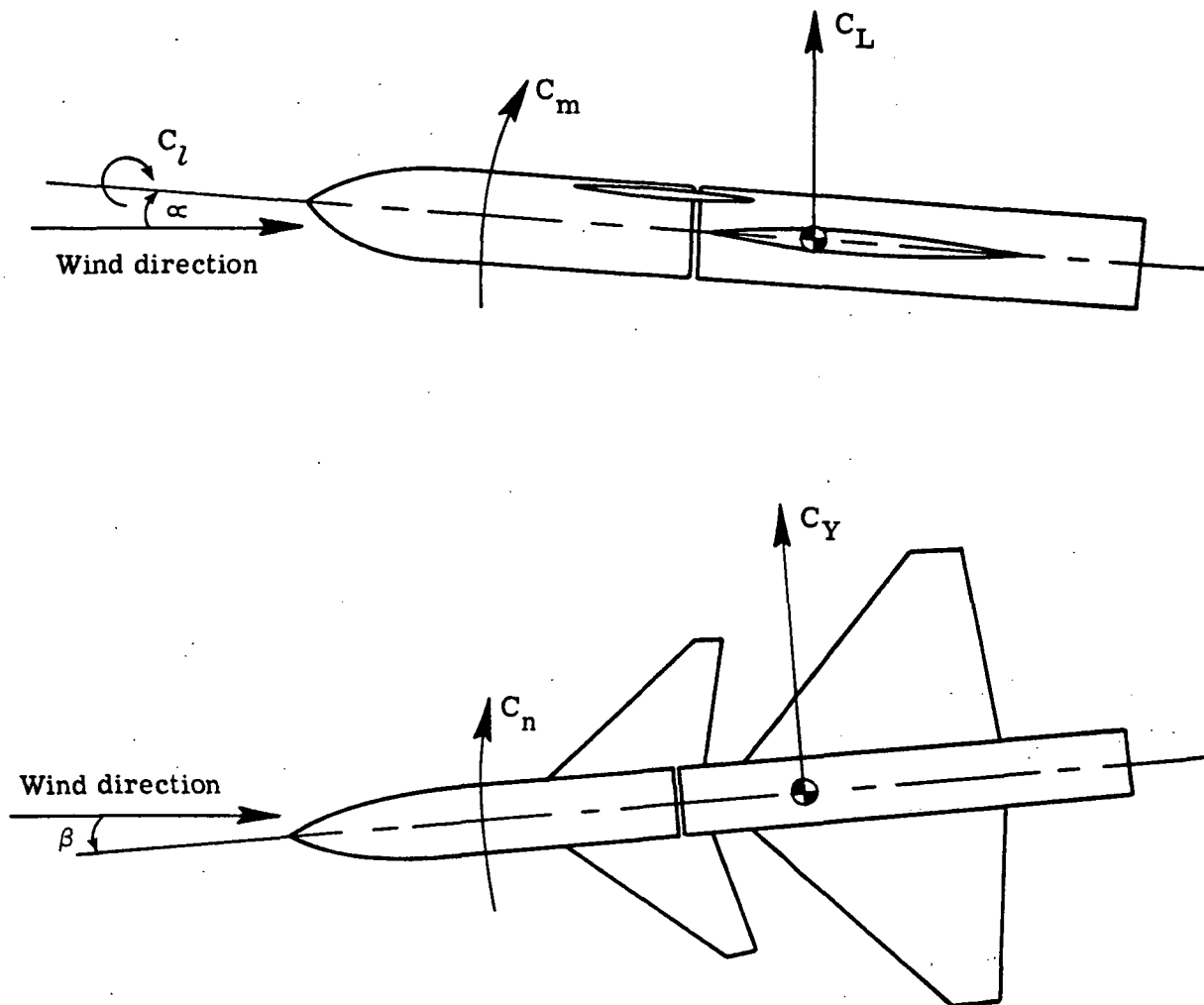
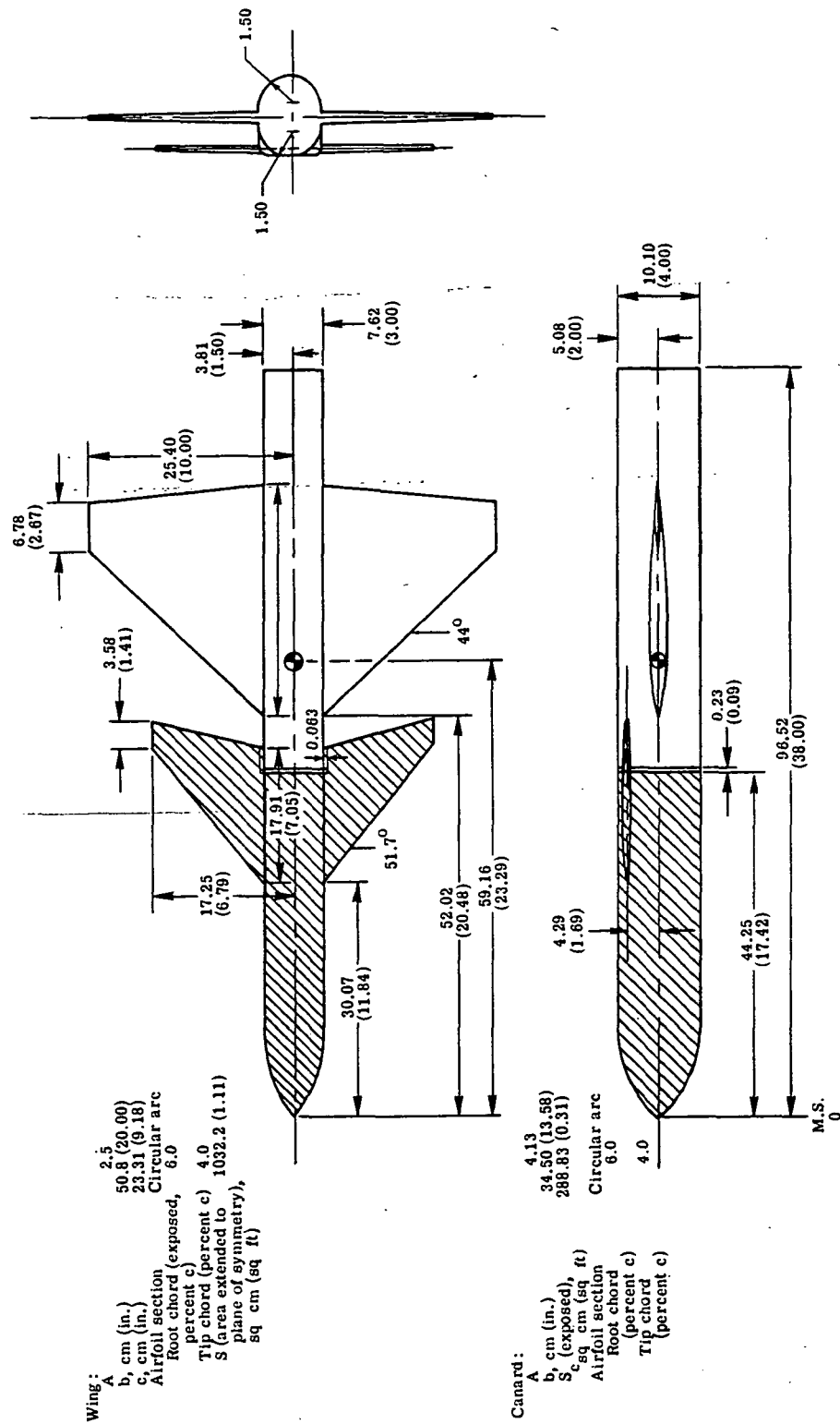


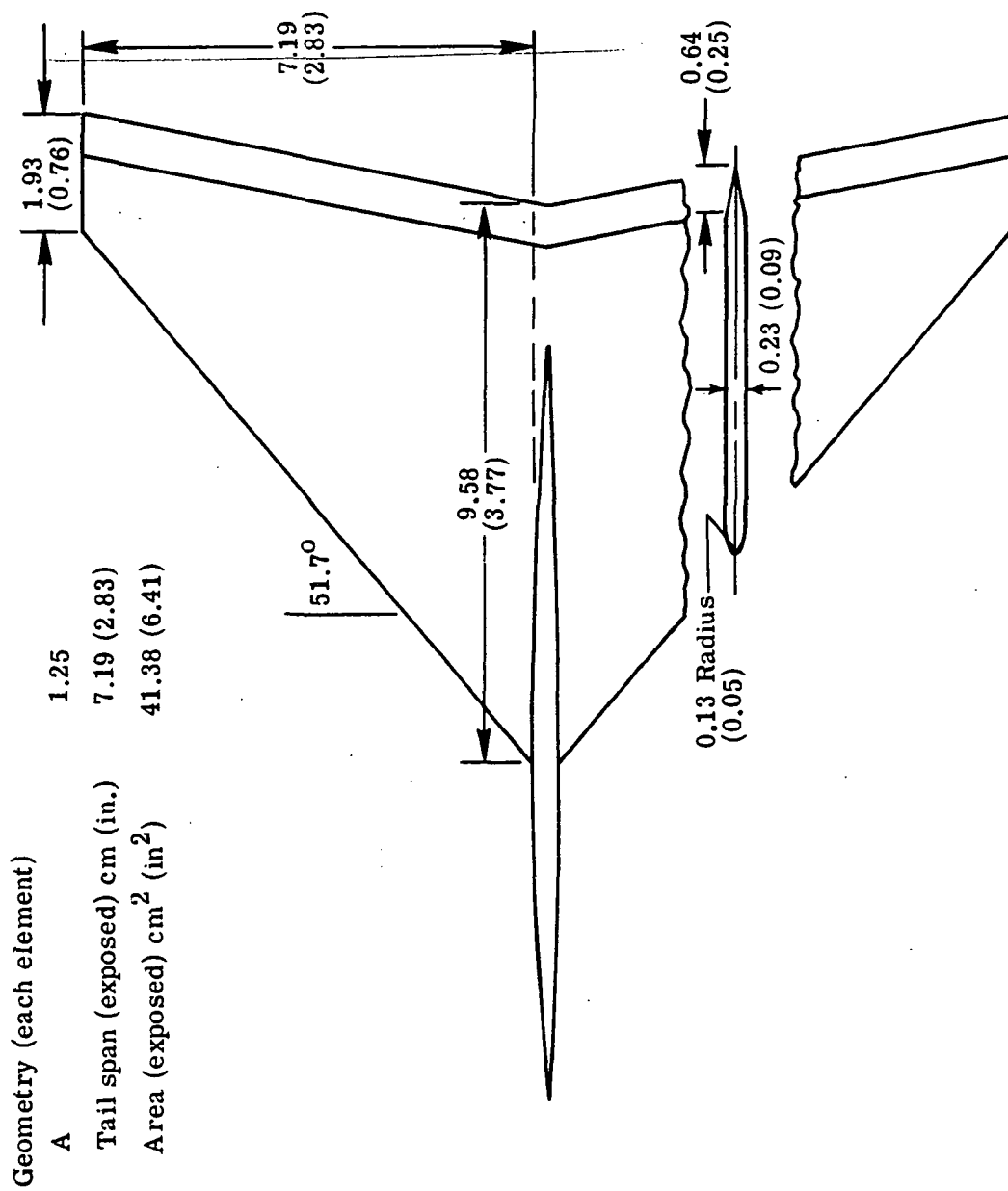
Figure 1.- System of axes used showing positive directions of forces, moments, angles, and velocities.



(a) Three-view drawing of test model.
 Figure 2.- Model drawings. (All dimensions in cm (in.).)

(b) Center-line vertical tail.

Figure 2.- Continued.



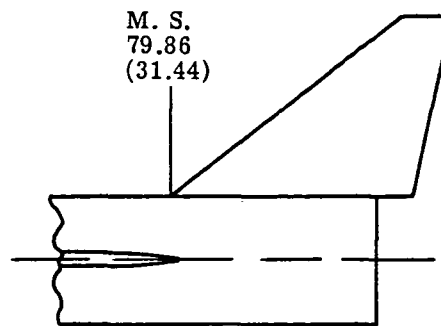
(c) Upper and lower surface wing-mounted vertical tails.

Figure 2.- Concluded.

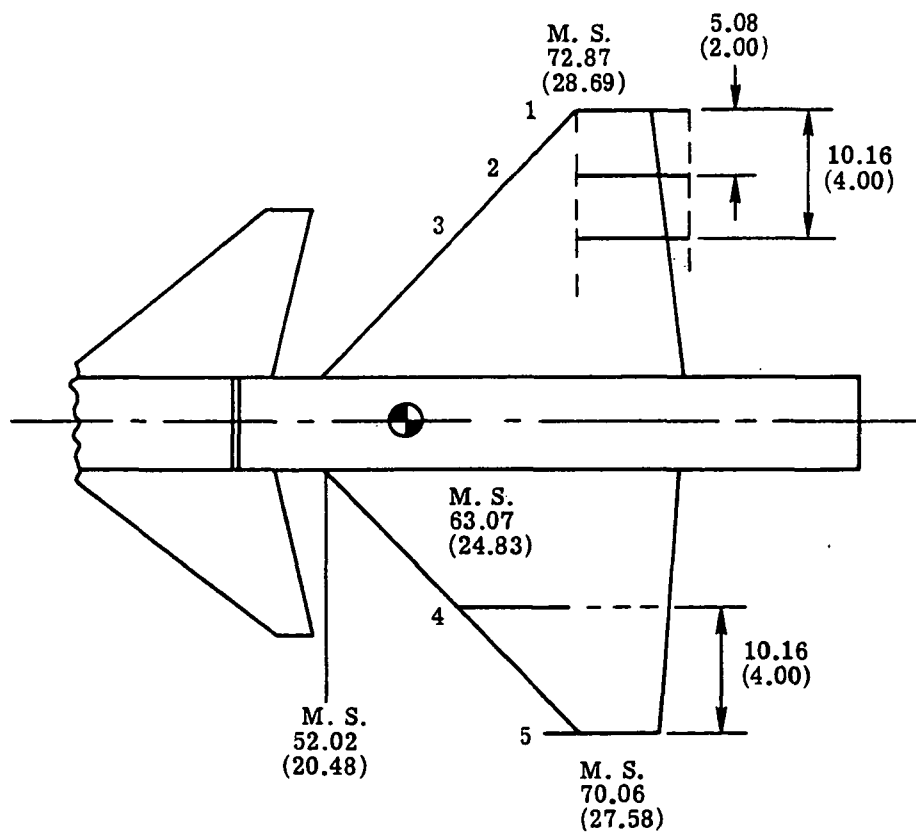


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Figure 3.- Model mounted in tunnel for testing.

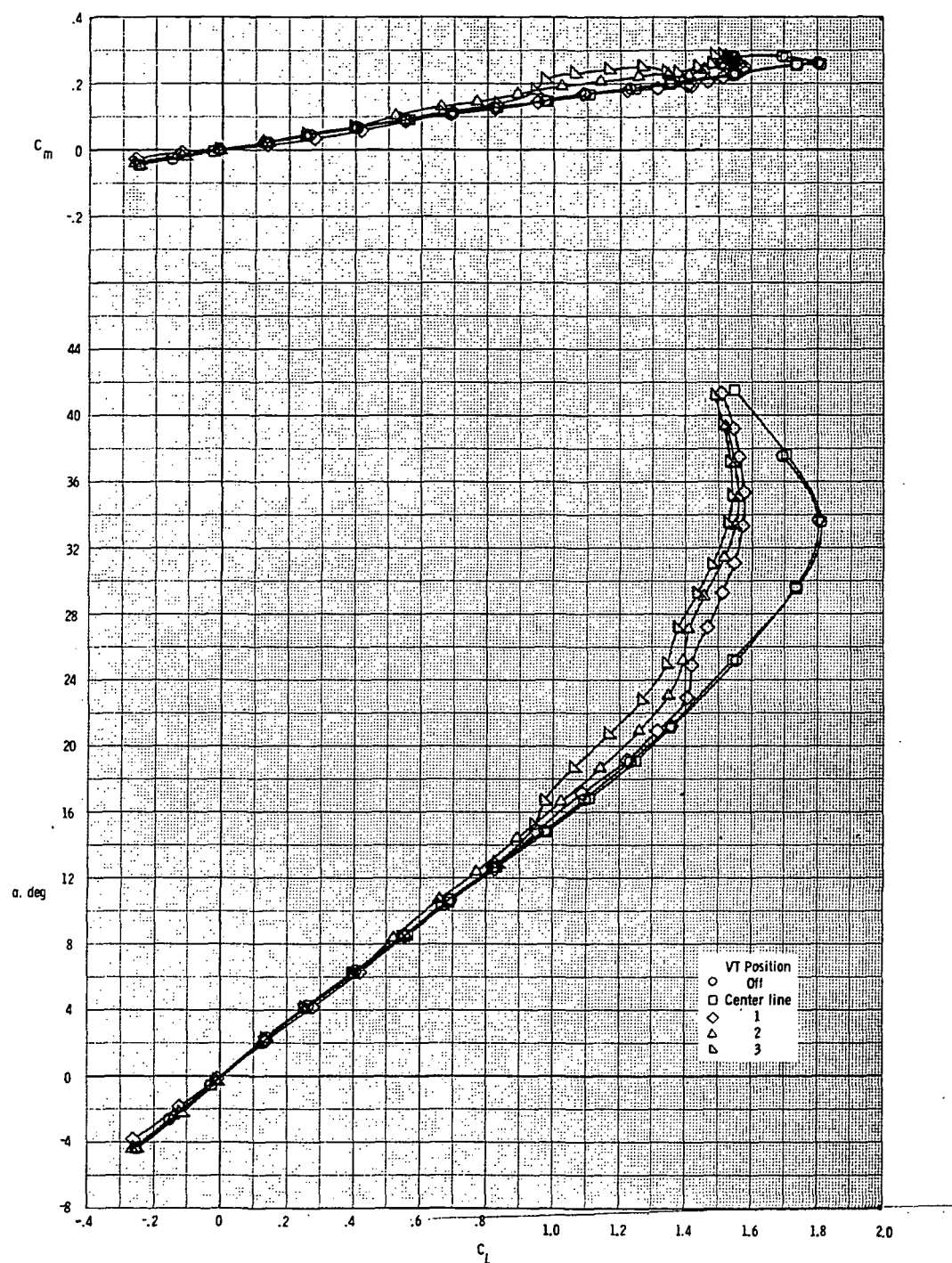


Center-line vertical tail



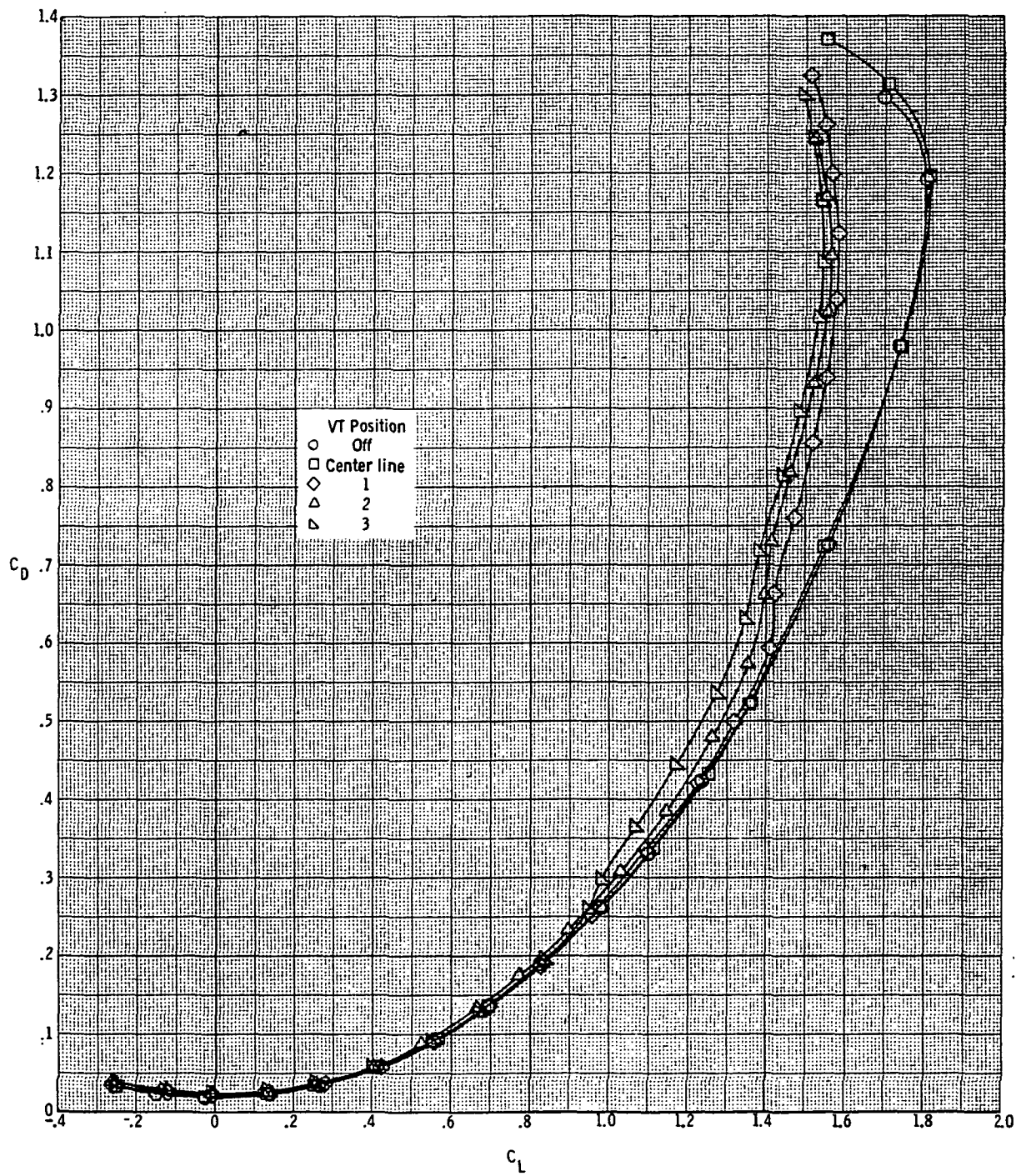
Wing-mounted vertical tails

Figure 4.- Location of the various vertical-tail configurations.
(All dimensions in cm (in.).)



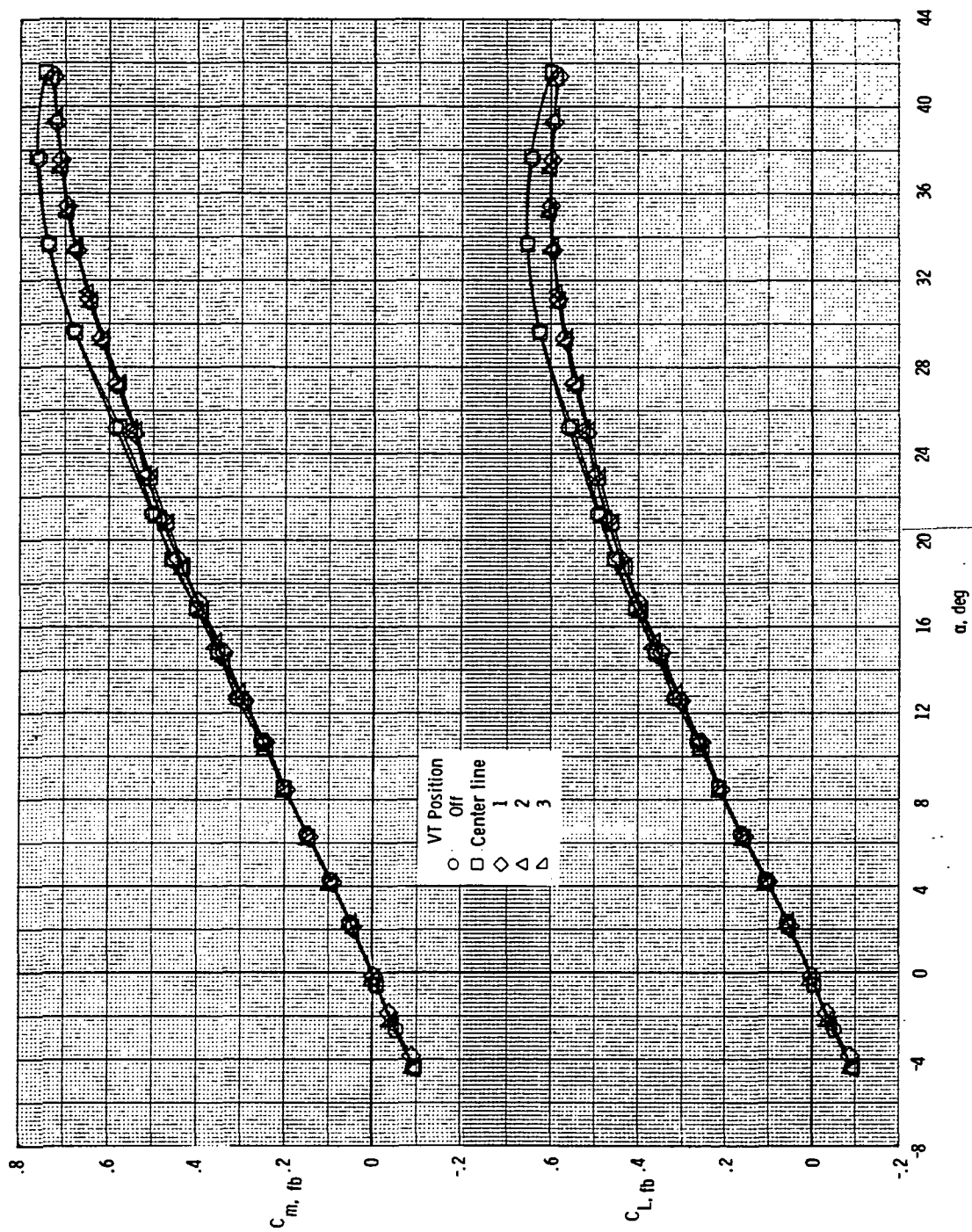
(a) Total longitudinal characteristics.

Figure 5.- Longitudinal aerodynamic characteristics of wing-body-canard configuration with center-line vertical tail or wing-mounted vertical tail at locations 1, 2, and 3.



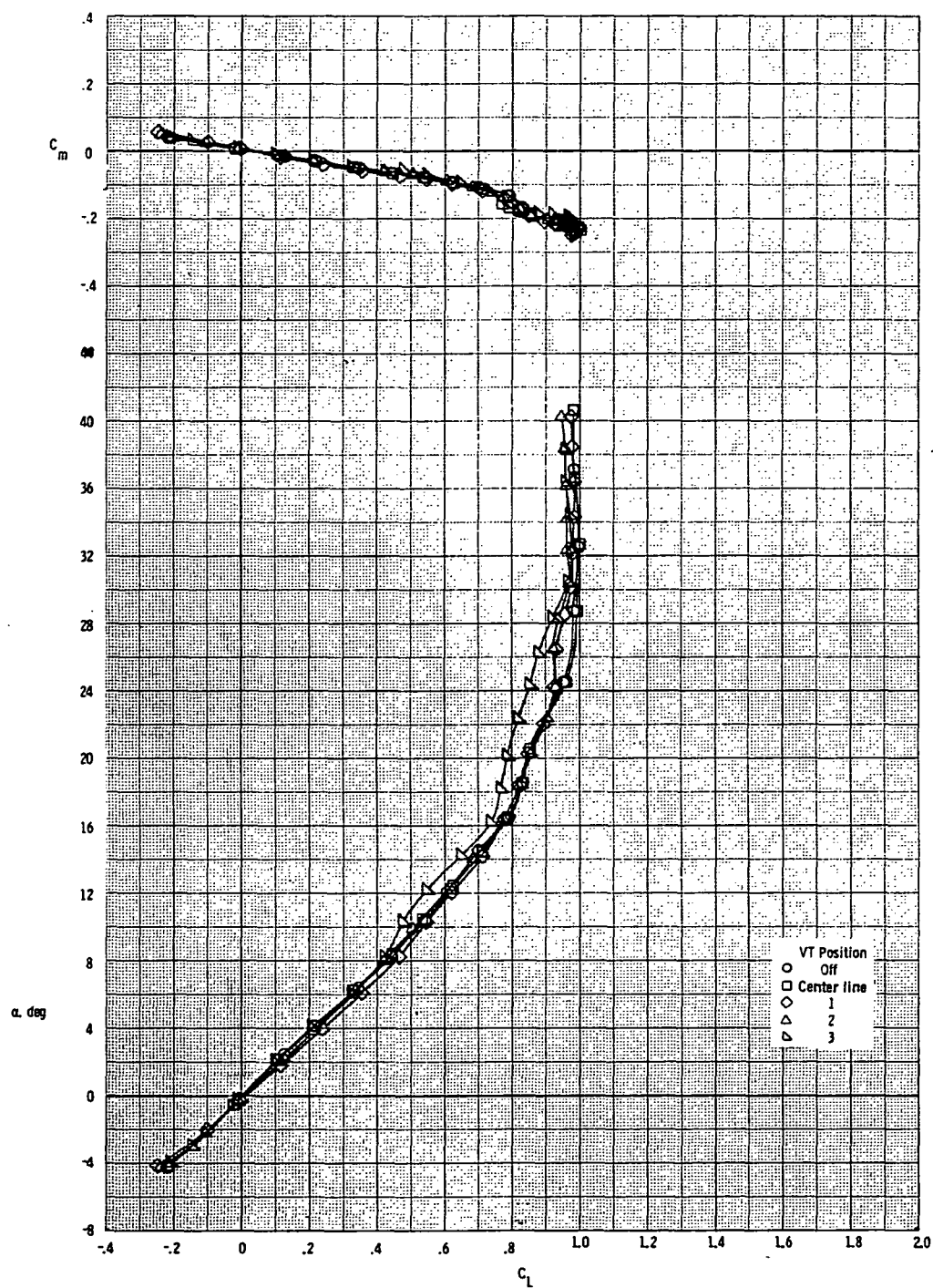
(a) Concluded.

Figure 5.- Continued.



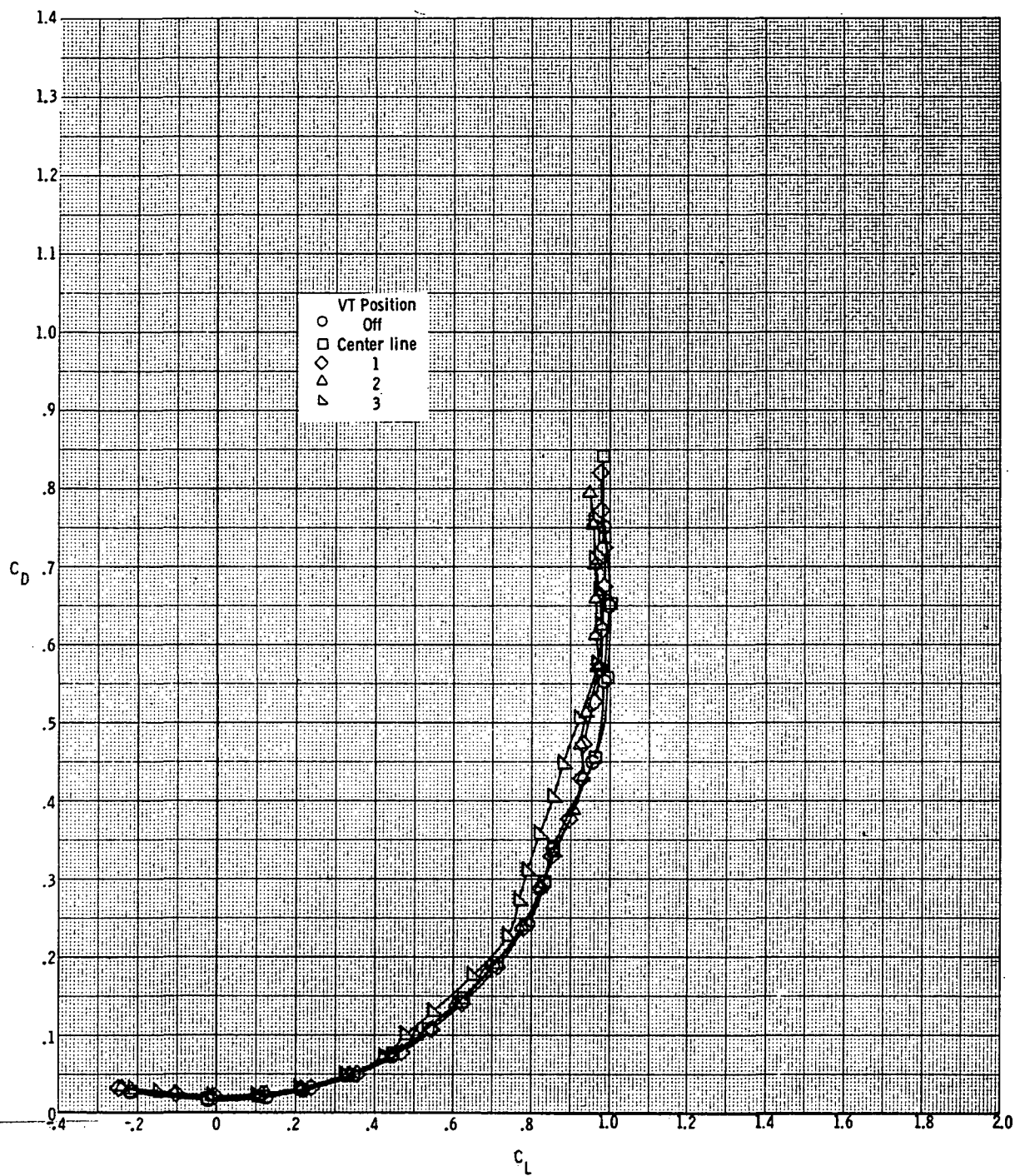
(b) Forward fuselage longitudinal characteristics.

Figure 5.- Concluded.



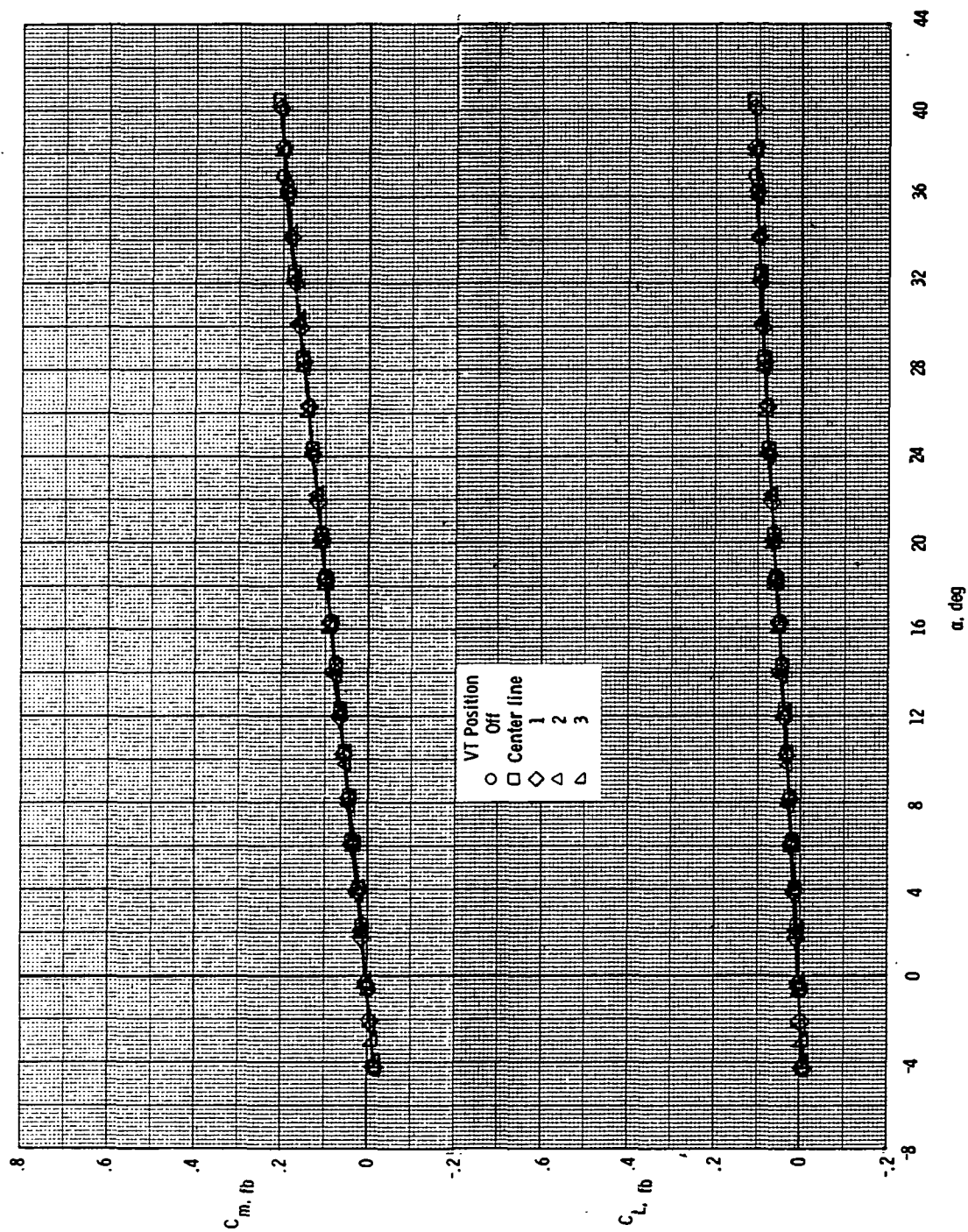
(a) Total longitudinal aerodynamic characteristics.

Figure 6.- Longitudinal aerodynamic characteristics of the wing-body configuration with center-line vertical tail or wing-mounted vertical tails at locations 1, 2, and 3.



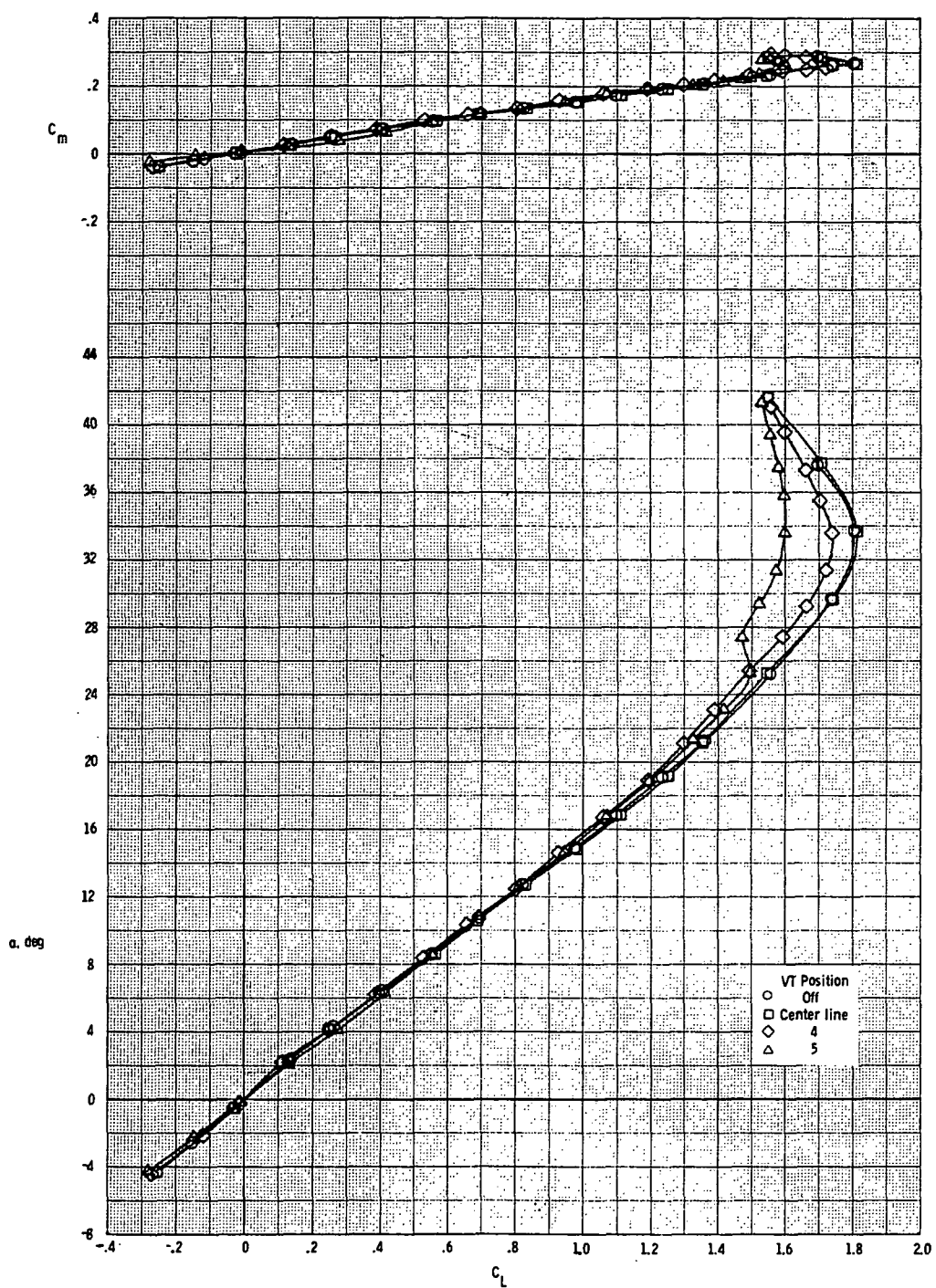
(a) Concluded.

Figure 6.- Continued.



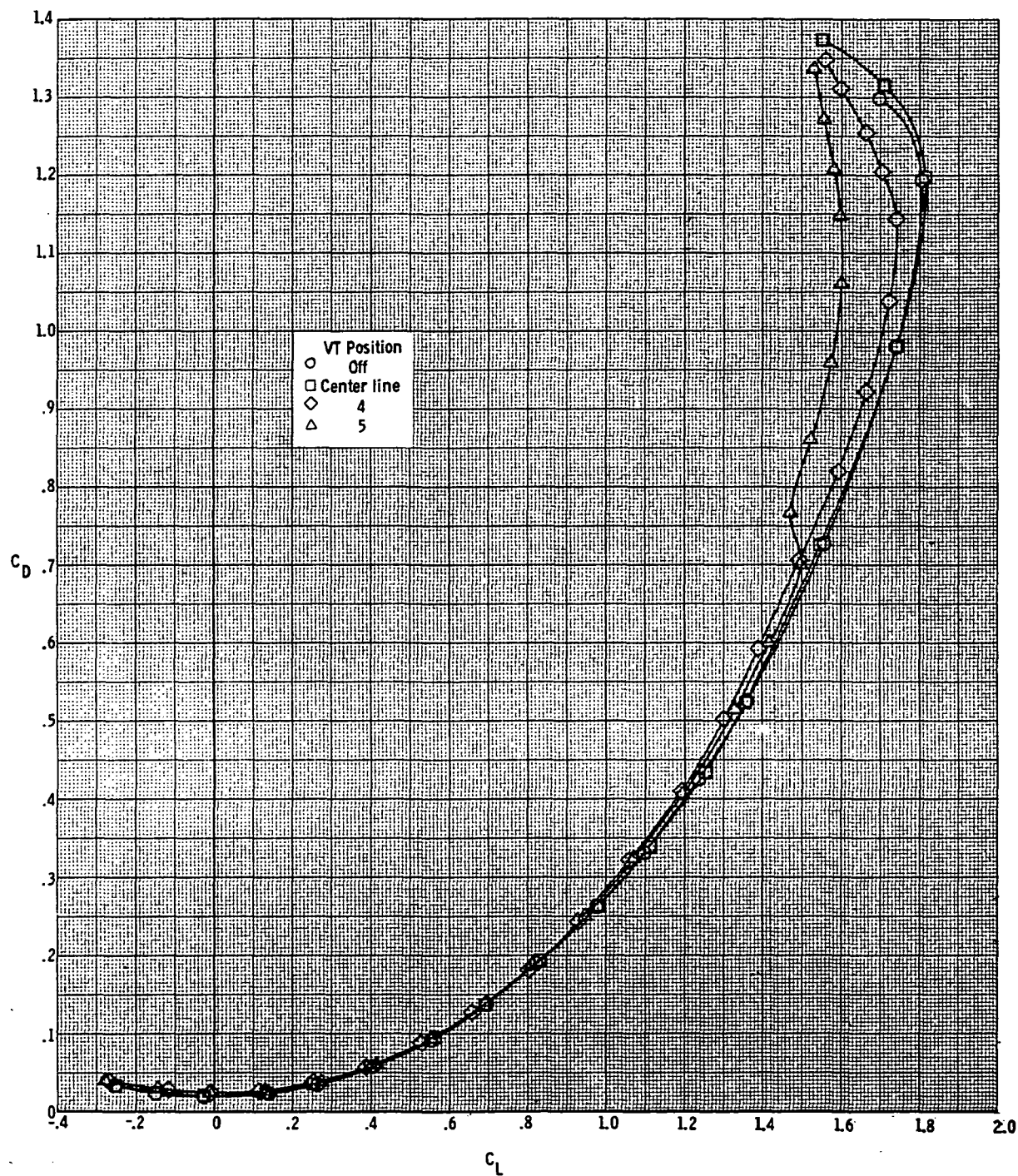
(b) Forward fuselage aerodynamic characteristics.

Figure 6.- Concluded.



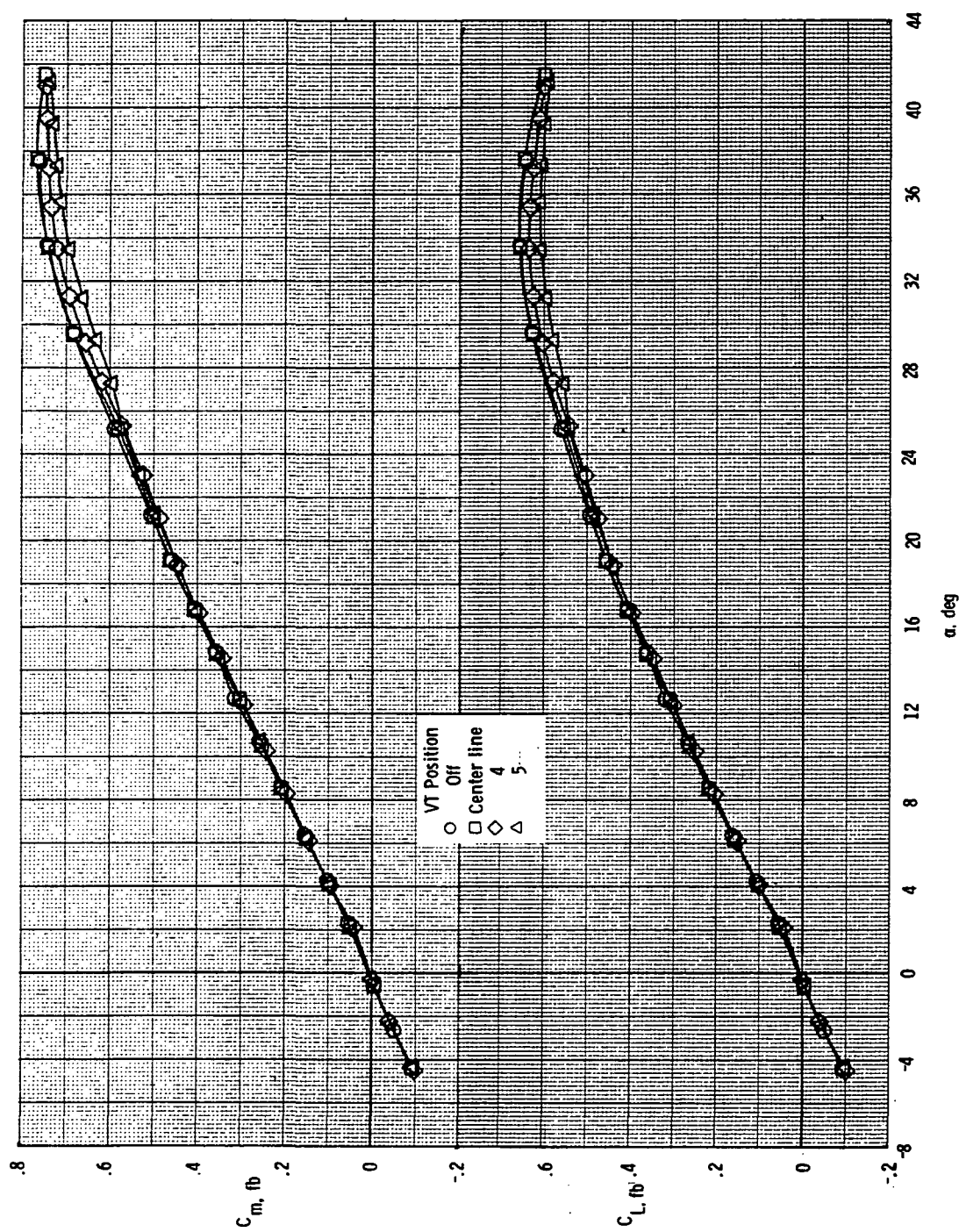
(a) Total longitudinal characteristics.

Figure 7.- Longitudinal aerodynamic characteristics of wing-body-canard configuration with center-line vertical tail or wing-mounted vertical tails at positions 4 and 5.



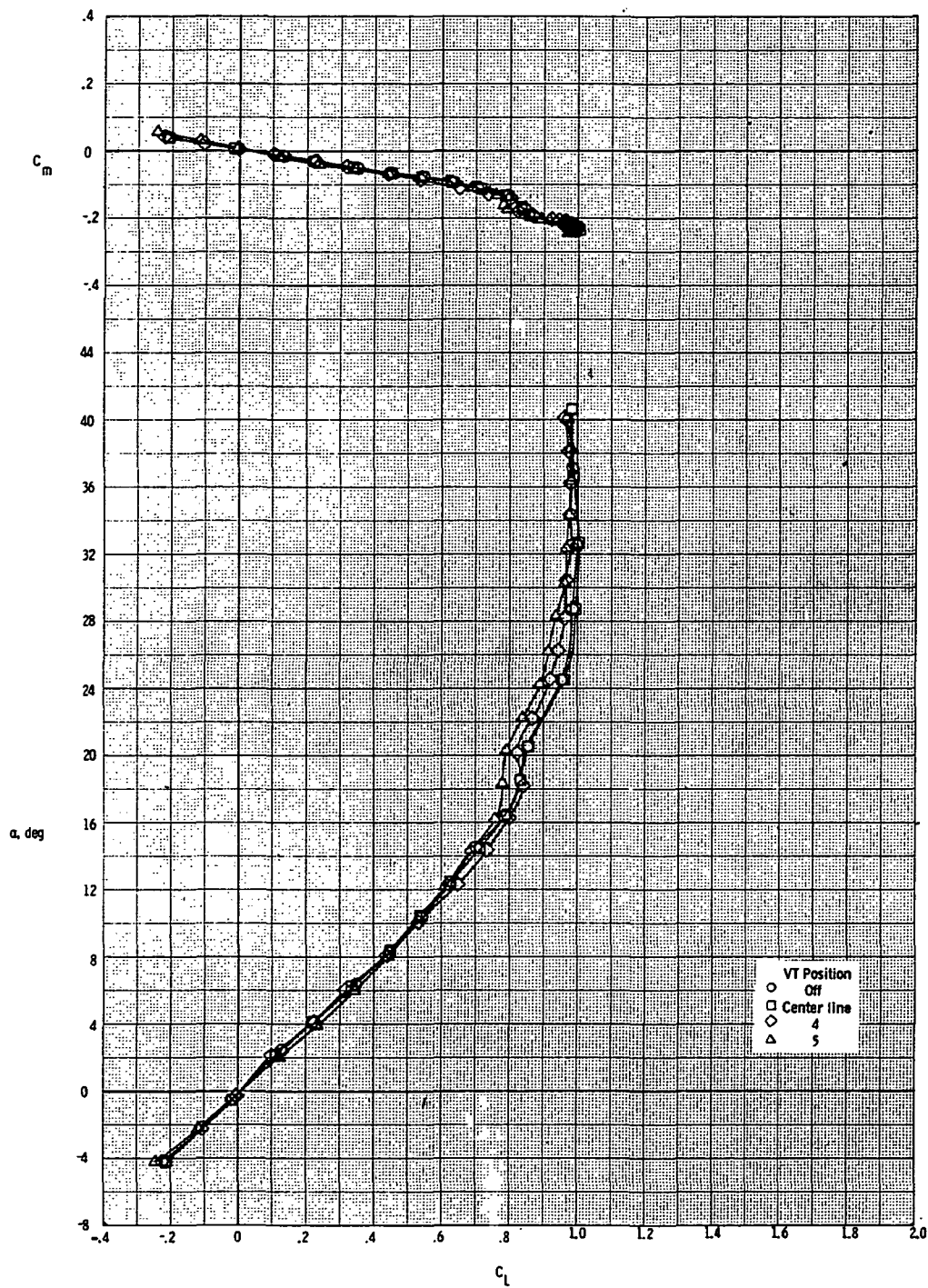
(a) Concluded.

Figure 7.- Continued.



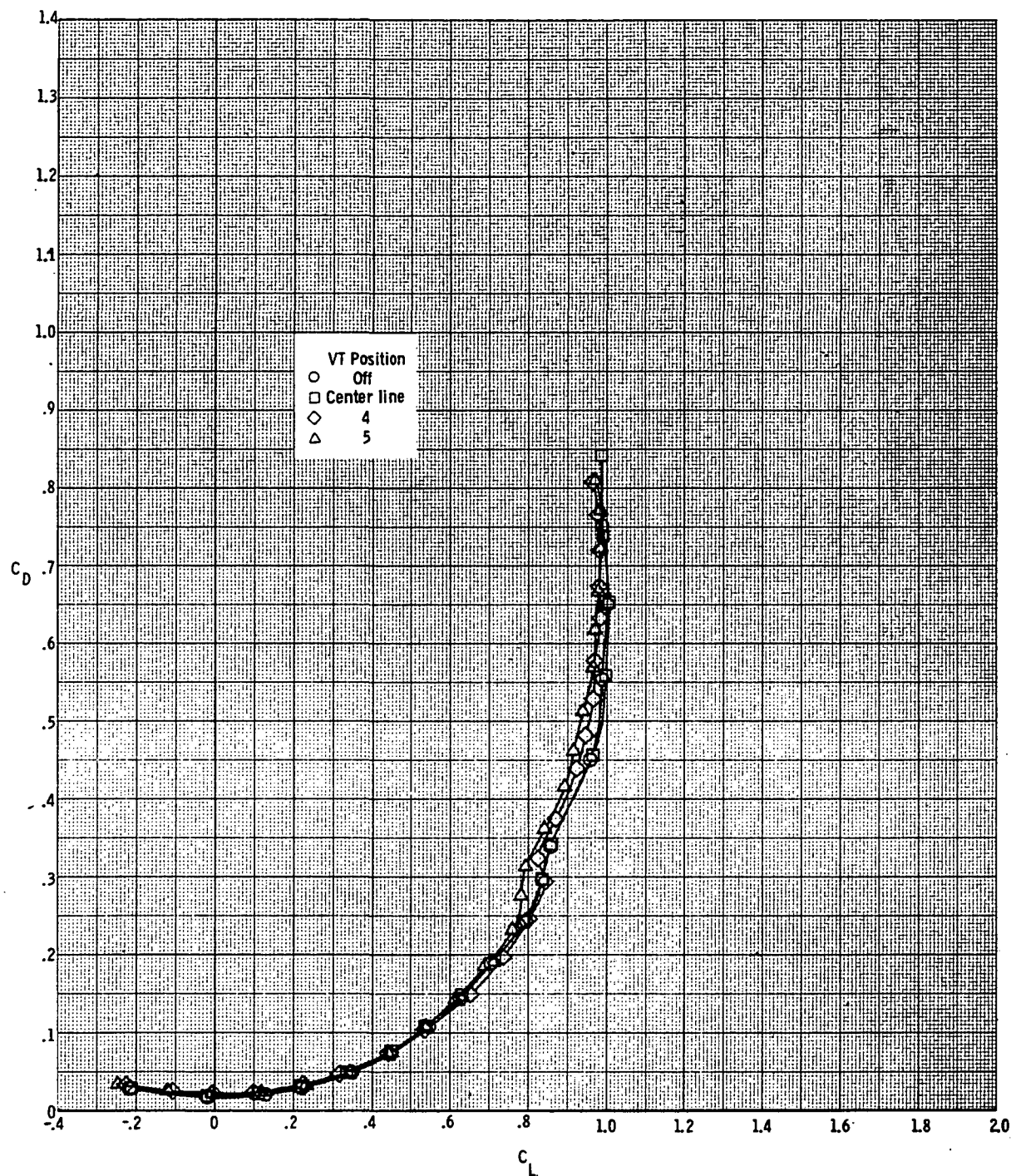
(b) Forward fuselage longitudinal characteristics.

Figure 7.- Concluded.



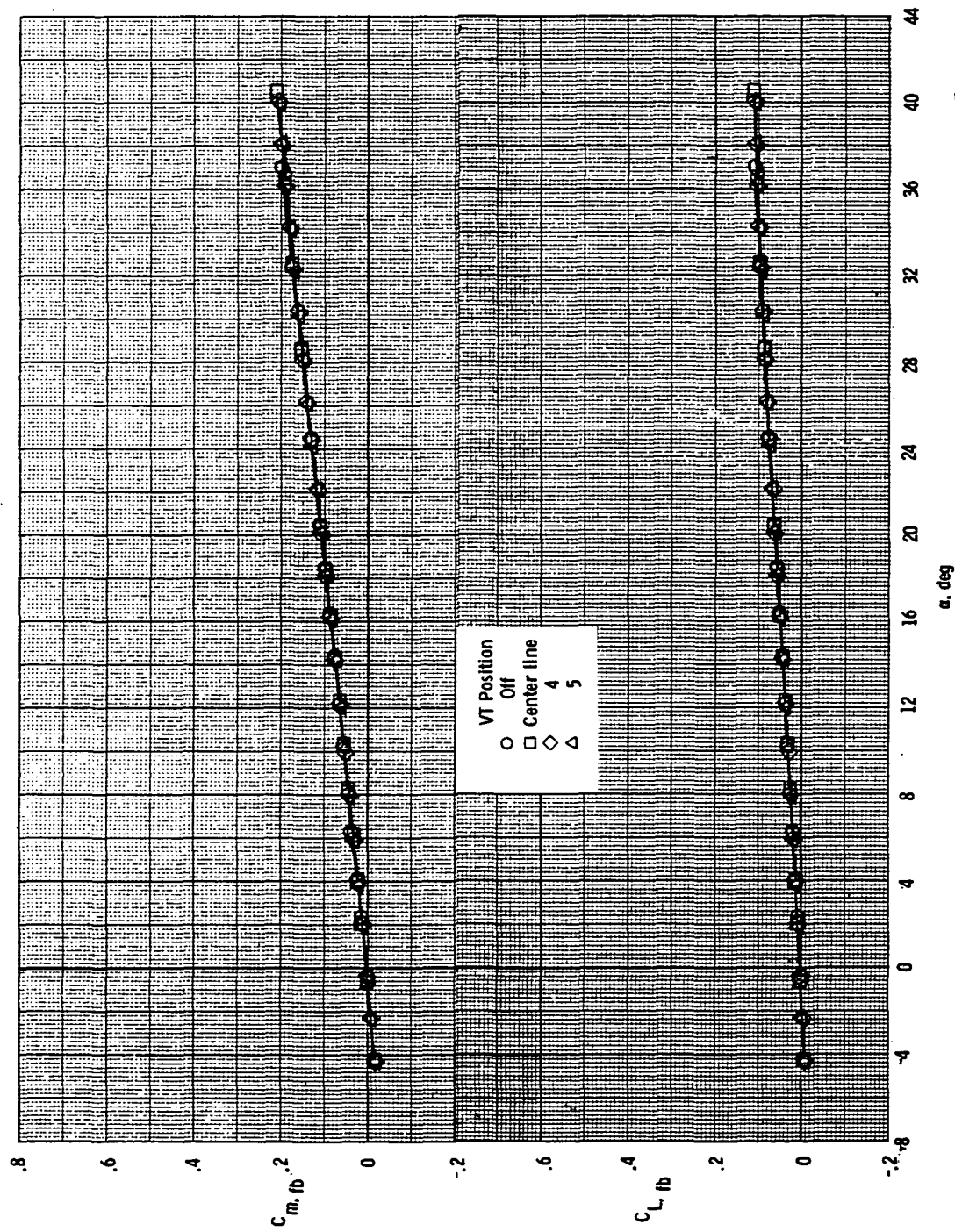
(a) Total longitudinal characteristics.

Figure 8.- Longitudinal aerodynamic characteristics of the wing-body configuration with center-line vertical tail or wing-mounted vertical tails at locations 4 and 5.



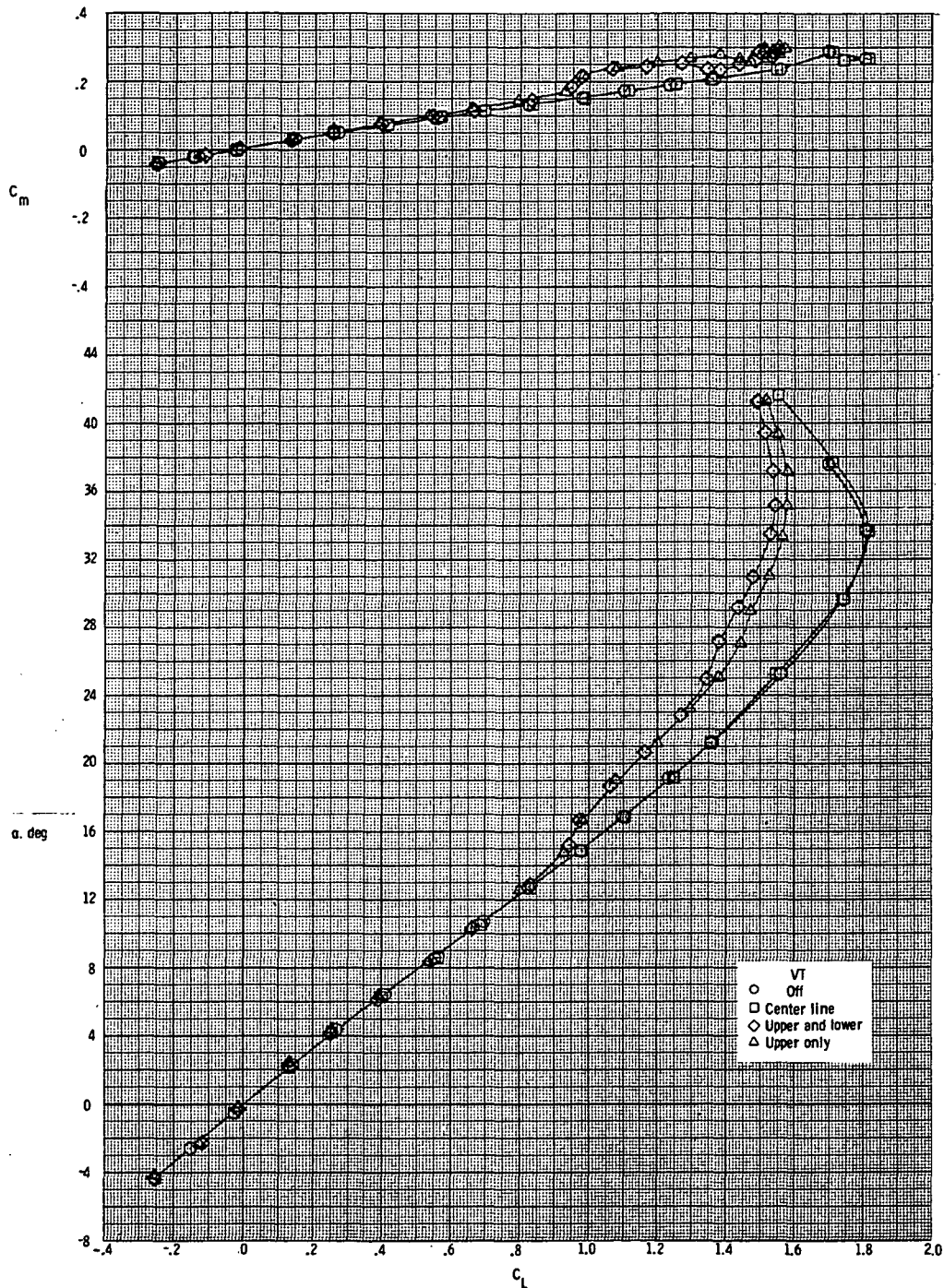
(a) Concluded.

Figure 8.- Continued.



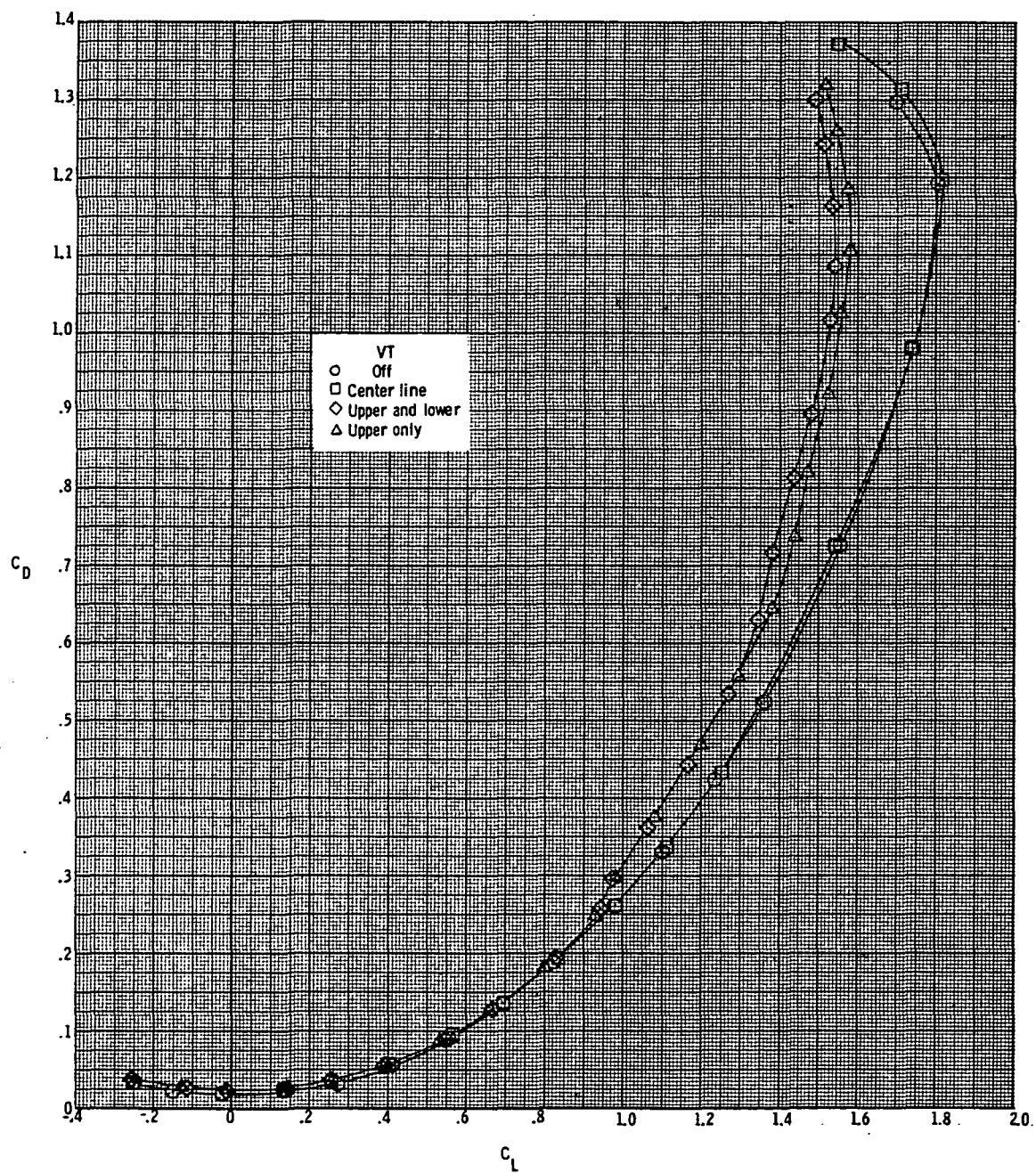
(b) Forward fuselage longitudinal characteristics.

Figure 8.- Concluded.



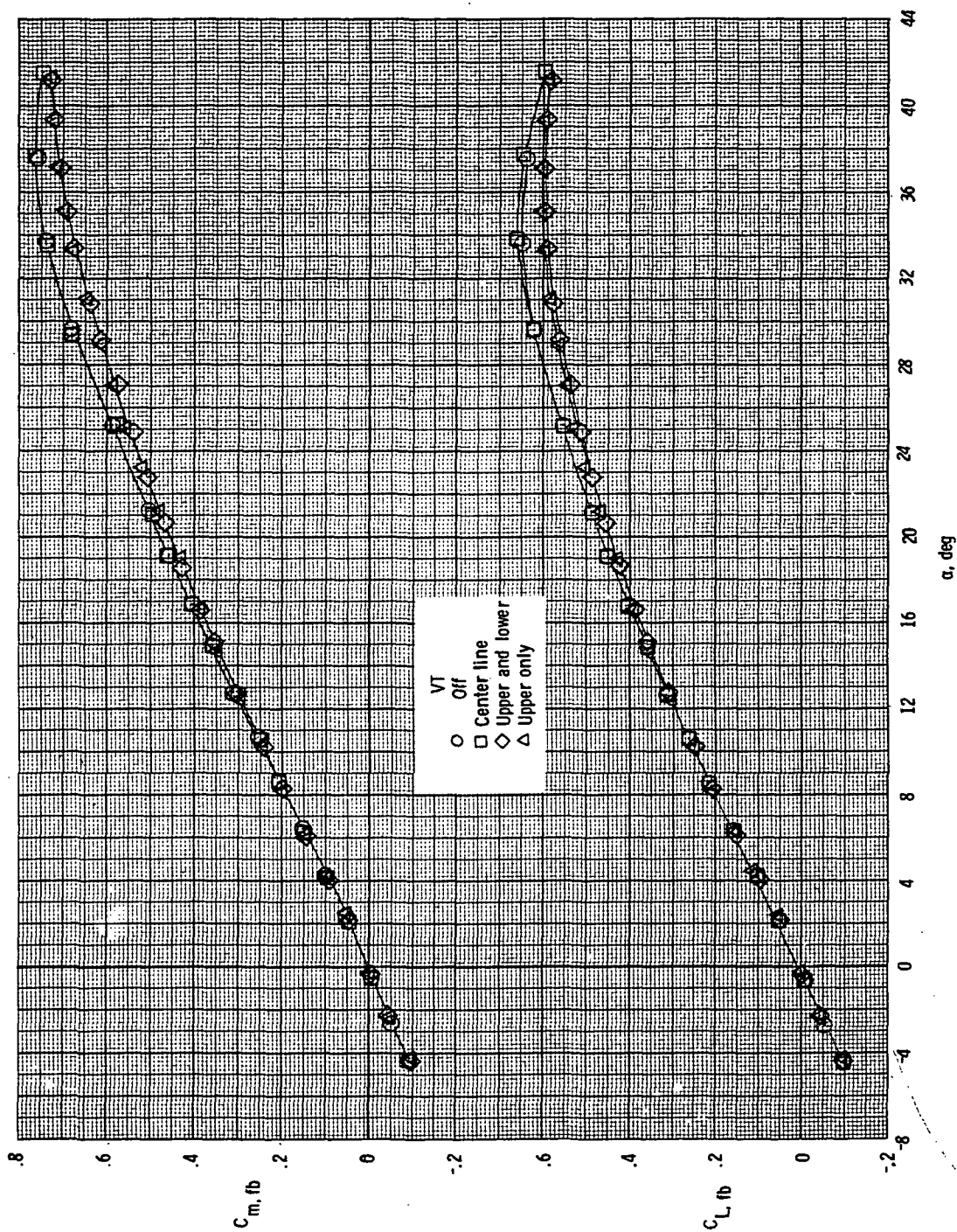
(a) Total longitudinal aerodynamic characteristics.

Figure 9.- Comparison of longitudinal aerodynamic characteristics of wing-body-canard configuration with center-line vertical tail or wing-mounted vertical tails with lower surface vertical tail on and off at location 3.



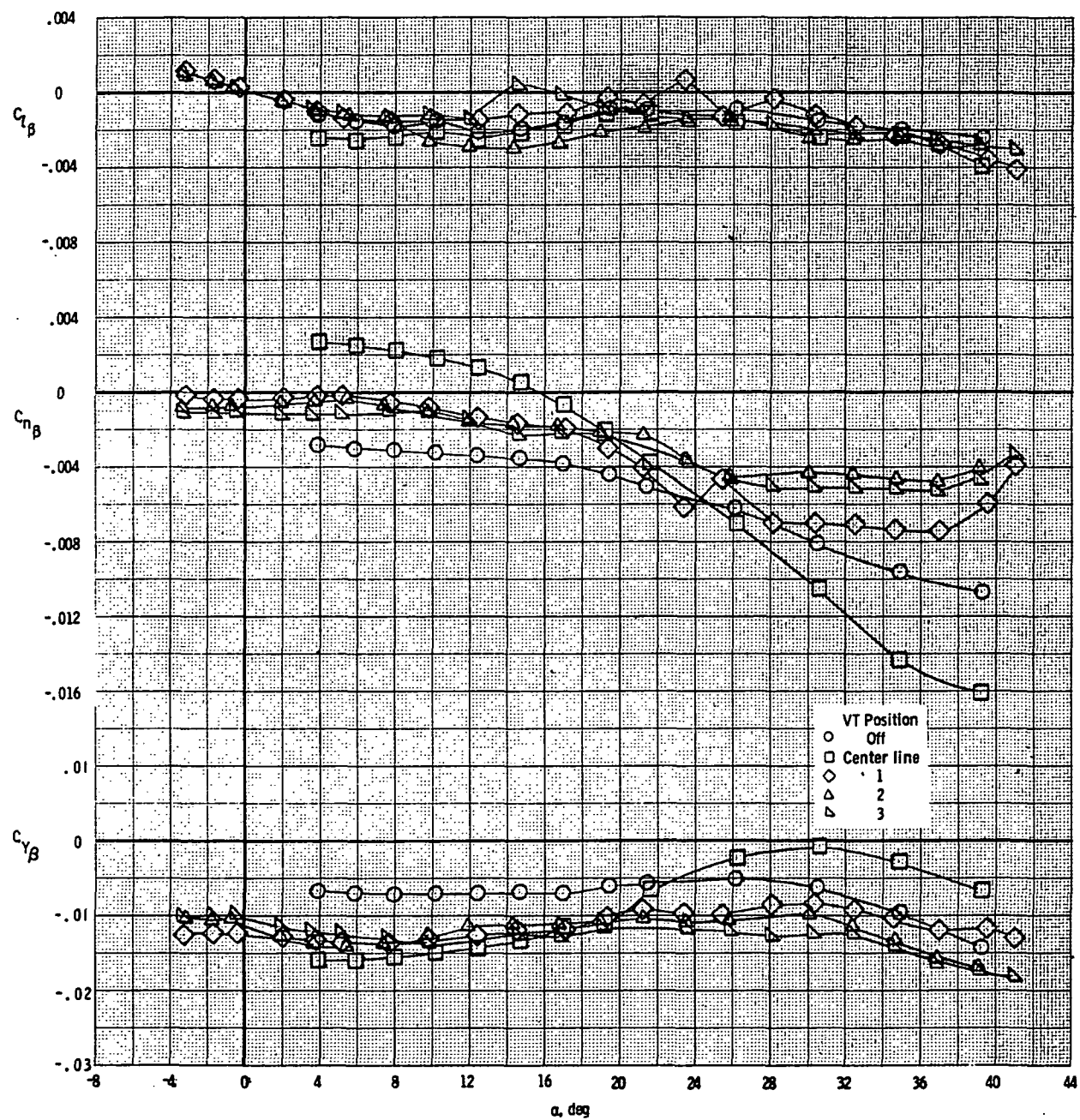
(a) Concluded.

Figure 9.- Continued.



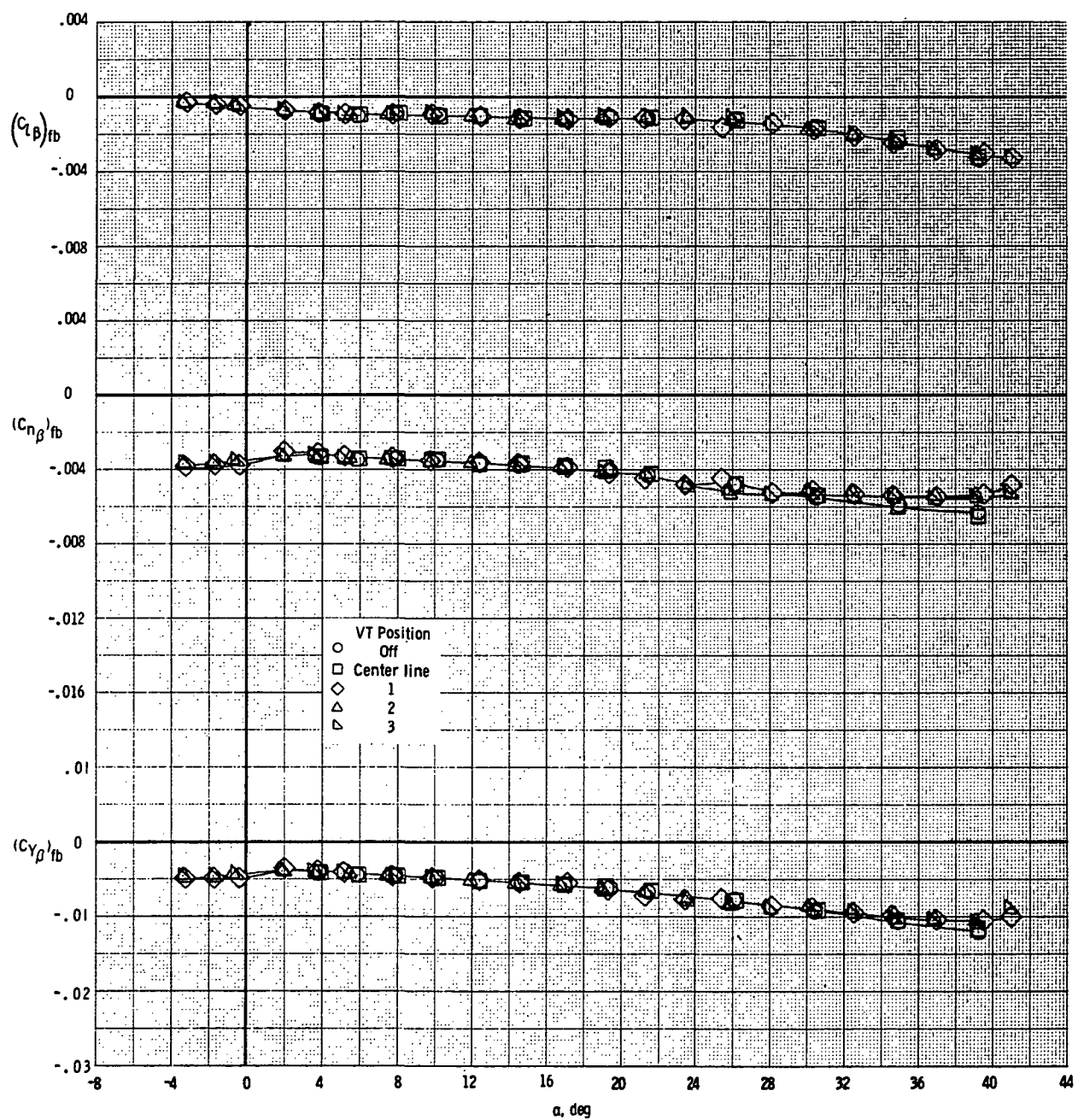
(b) Forward fuselage longitudinal aerodynamic characteristics.

Figure 9.- Concluded.



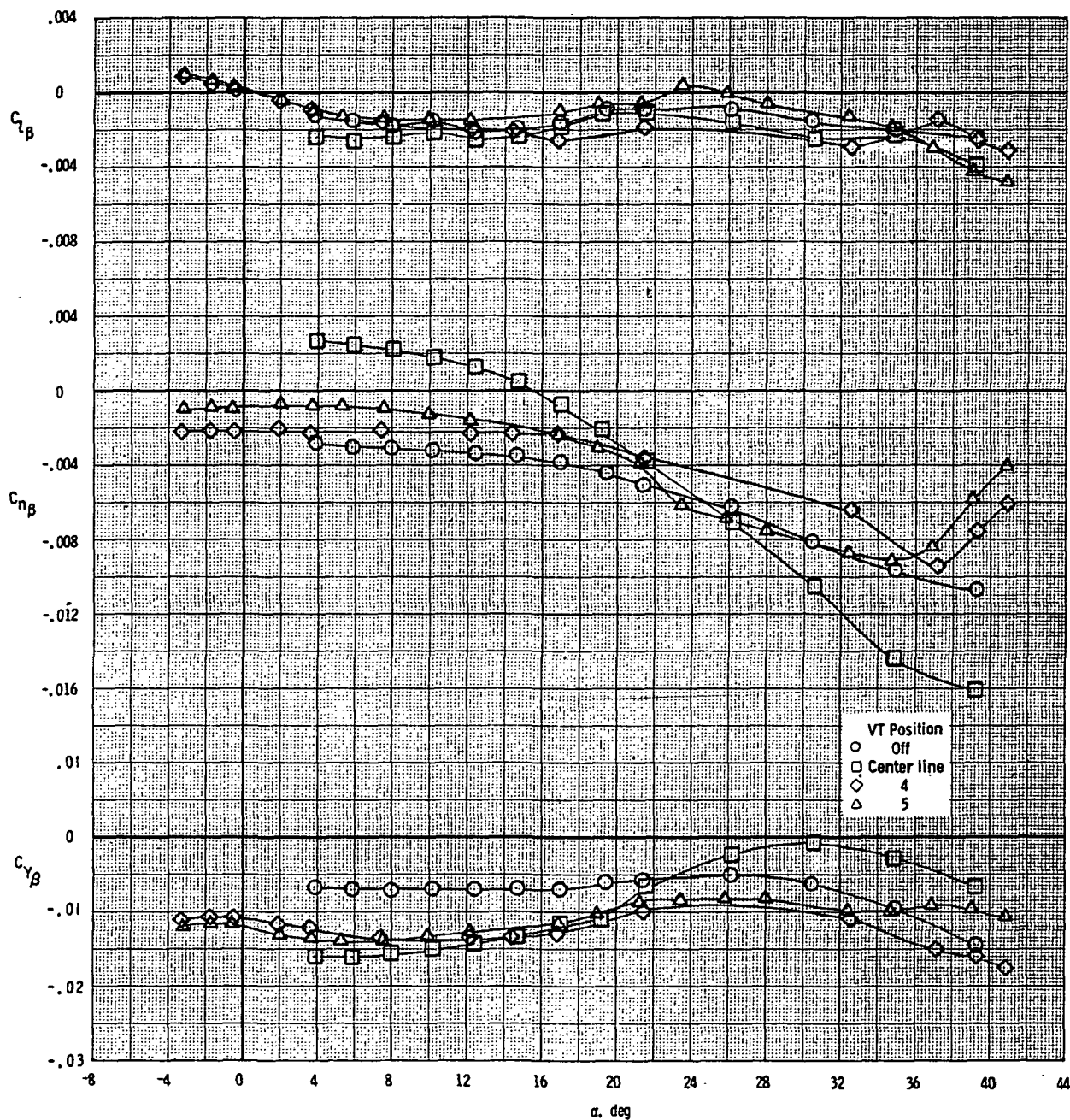
(a) Total derivatives.

Figure 10.- Lateral-directional derivatives for wing-body-canard configuration with center-line vertical tail or wing-mounted vertical tails at locations 1, 2, and 3.



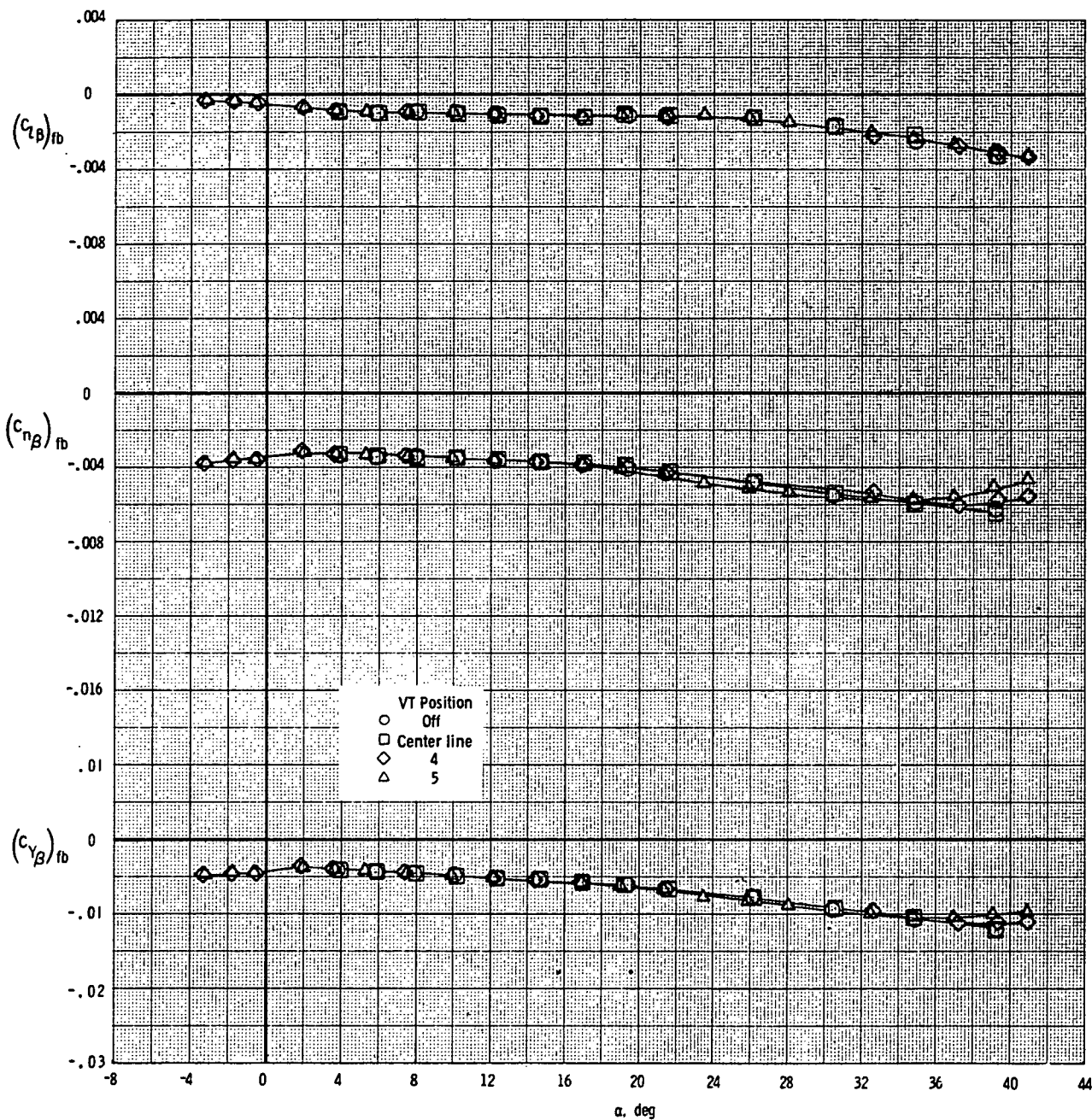
(b) Forward fuselage derivatives.

Figure 10.- Concluded.



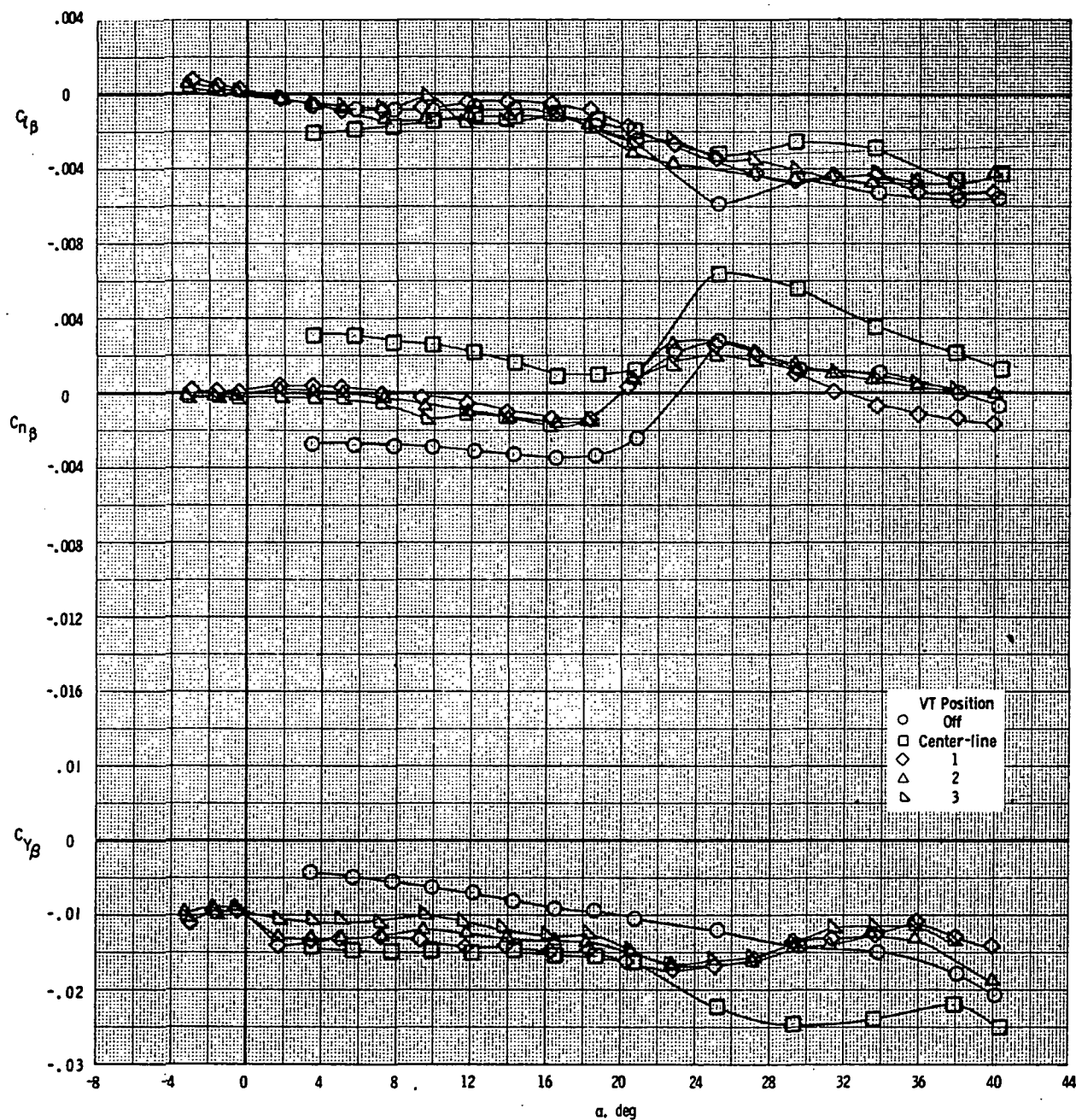
(a) Total derivatives.

Figure 11.- Lateral-directional derivatives for wing-body-canard configuration with center-line vertical tail or wing-mounted vertical tails at locations 4 and 5.



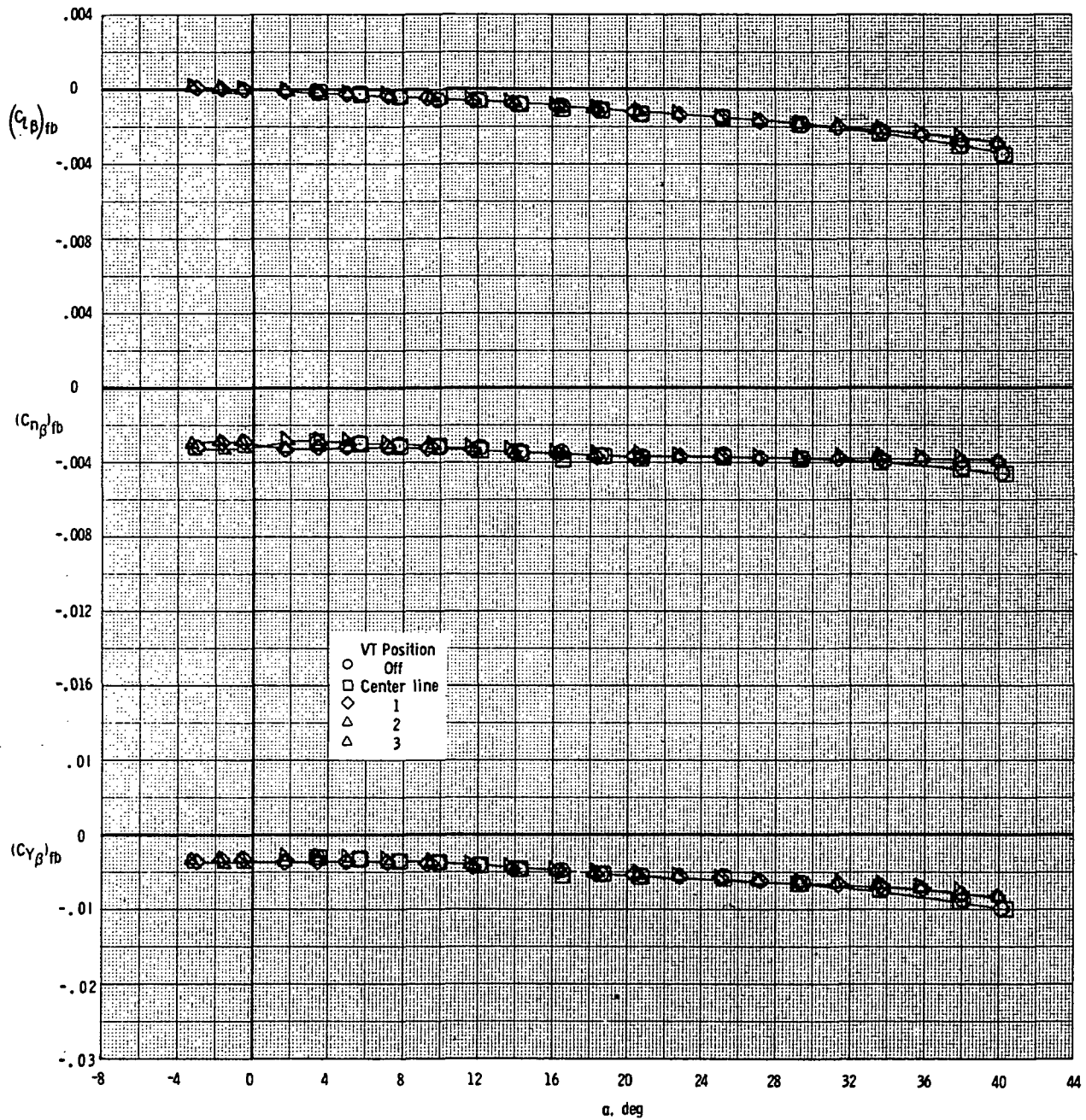
(b) Forward fuselage derivatives.

Figure 11.- Concluded.



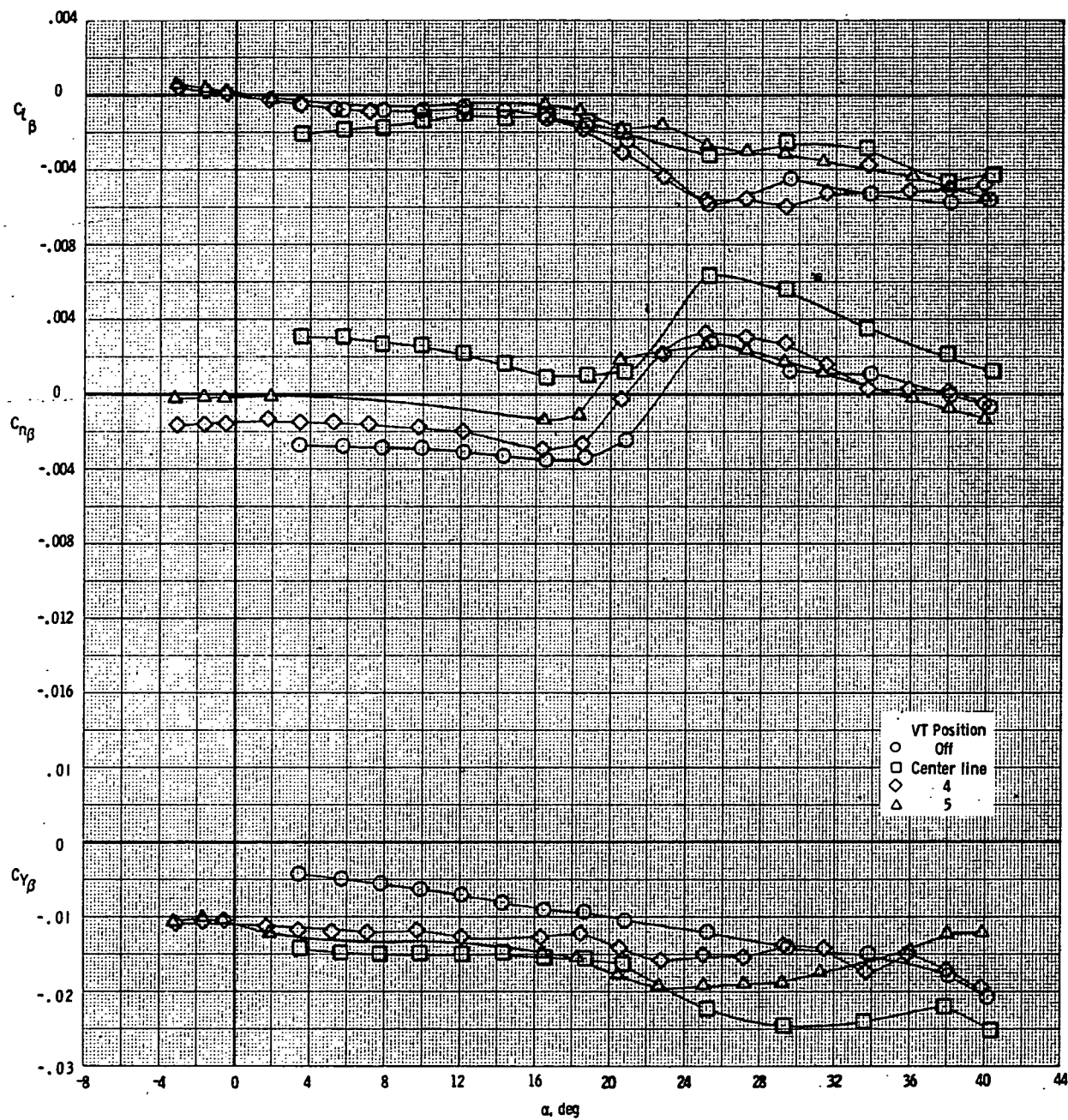
(a) Total derivatives.

Figure 12.- Lateral-directional derivatives for wing-body configuration with center-line vertical tail or wing-mounted vertical tails at locations 1, 2, and 3.



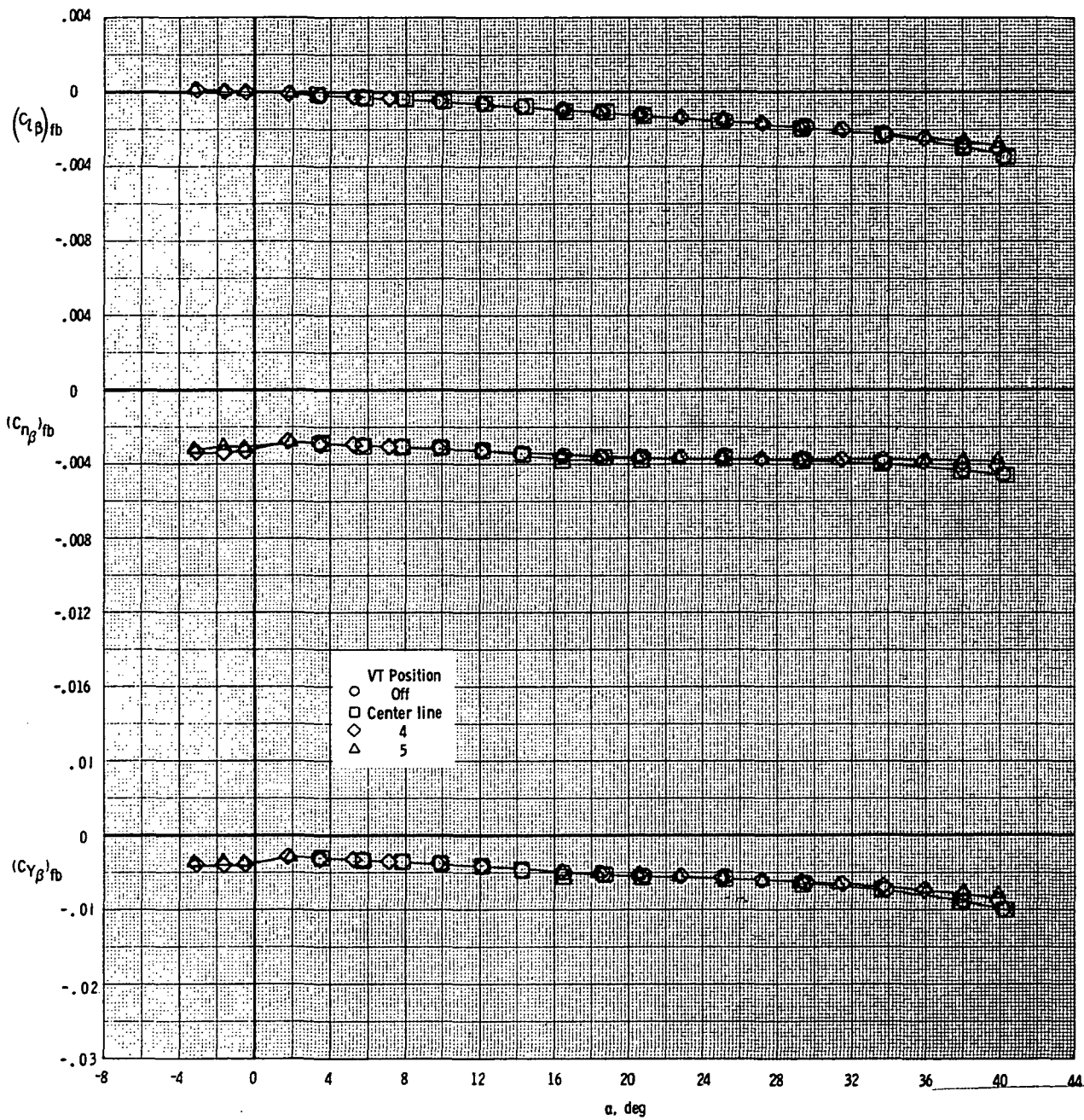
(b) Forward fuselage derivatives.

Figure 12.- Concluded.



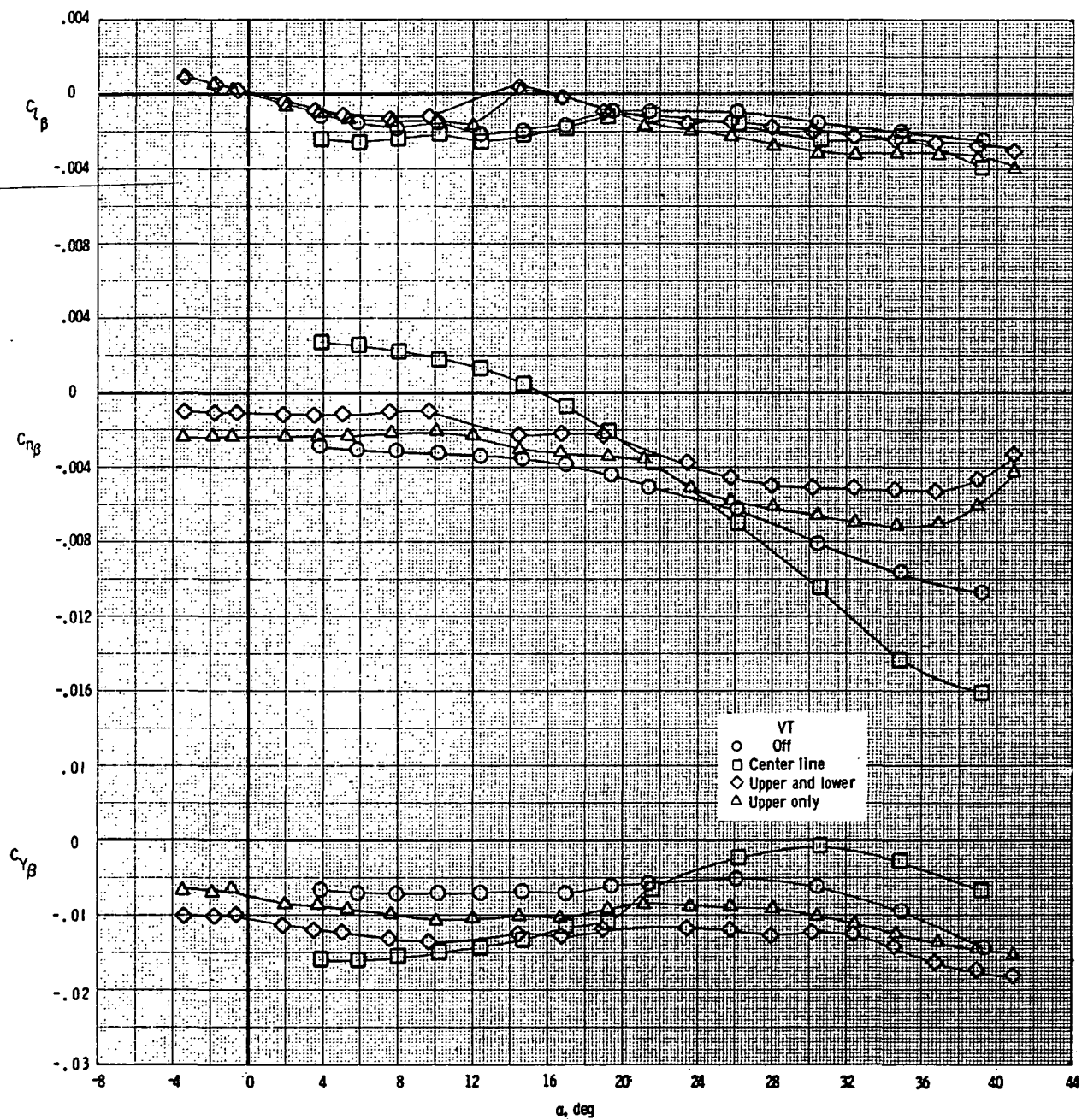
(a) Total derivatives.

Figure 13.- Lateral-directional derivatives for wing-body configuration with center-line vertical tail or wing-mounted vertical tails at locations 4 and 5.



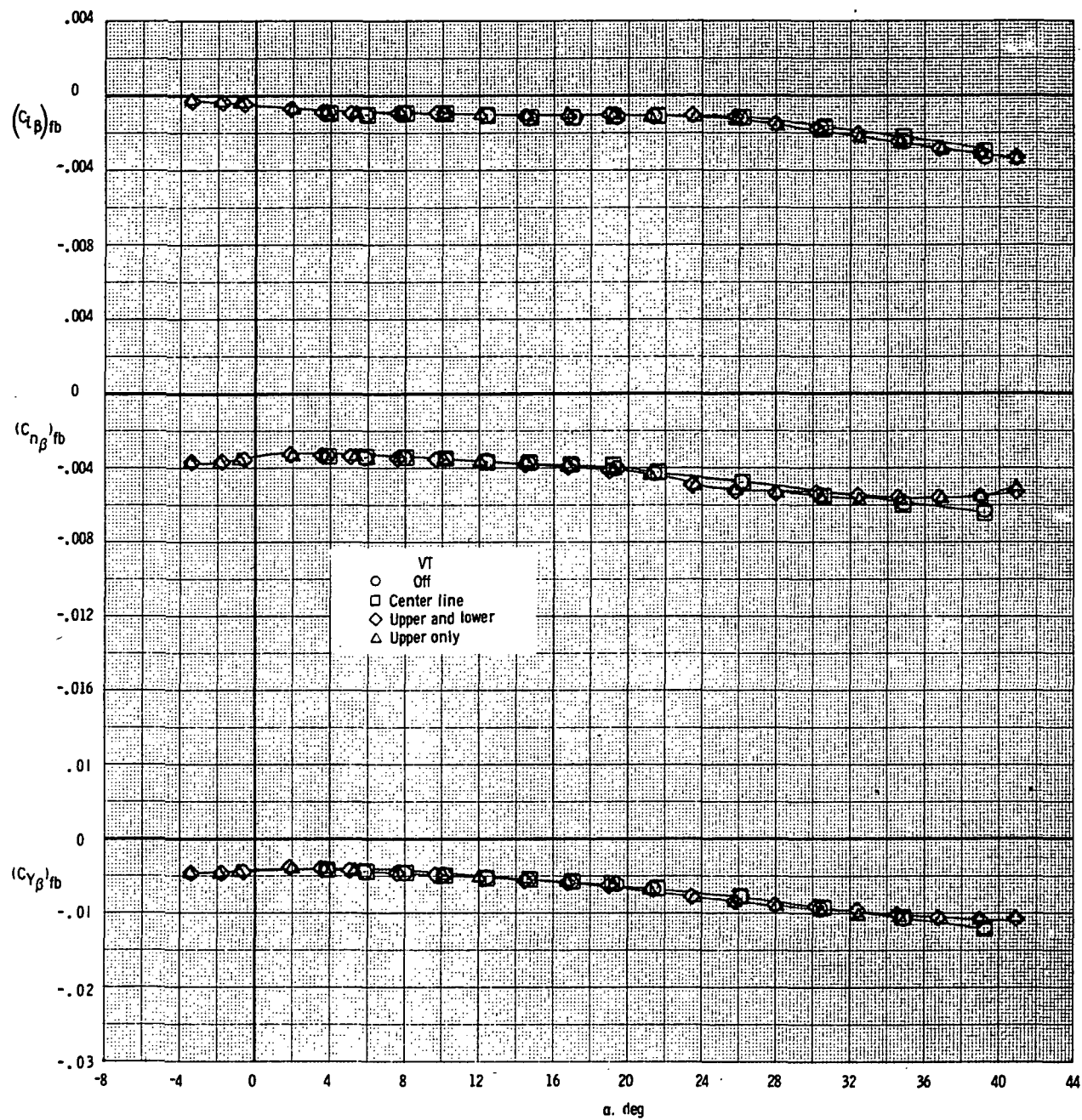
(b) Forward fuselage derivatives.

Figure 13.- Concluded.



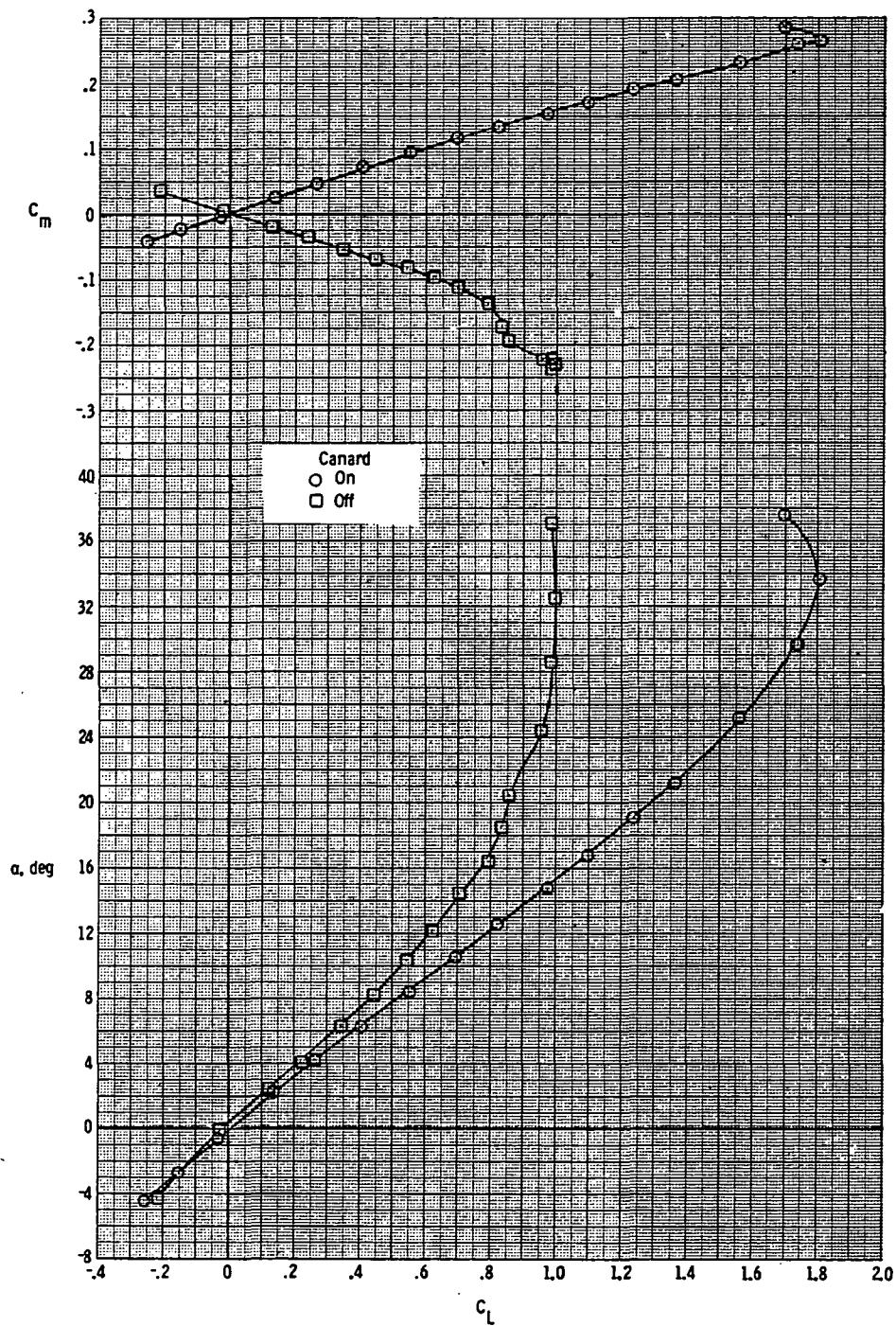
(a) Total derivatives.

Figure 14.- Comparison of lateral-directional derivatives of wing-body-canard configuration with center-line vertical tail or wing-mounted vertical tails with the lower surface vertical tail on and off at location 3.



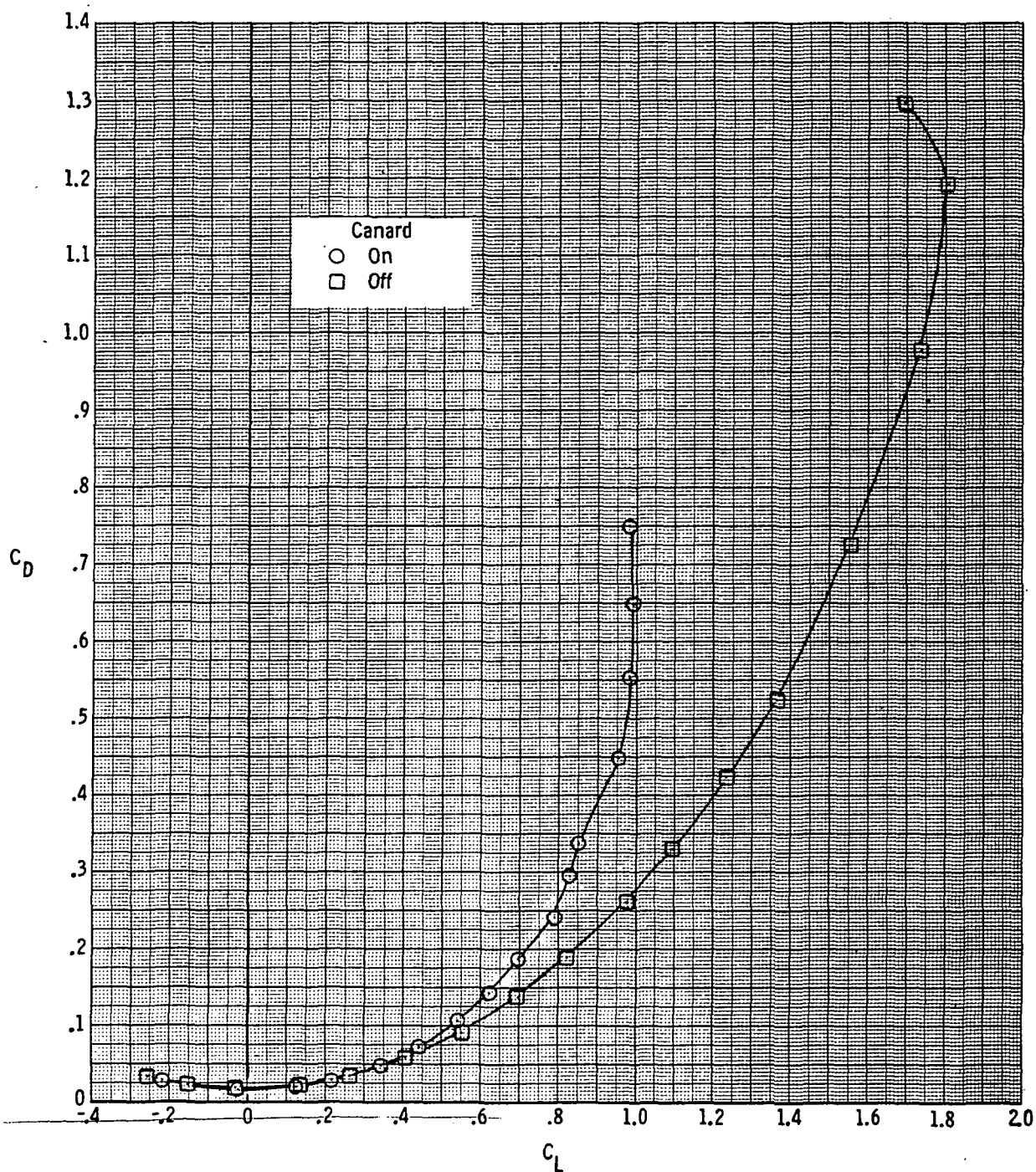
(b) Forward fuselage derivatives.

Figure 14.- Concluded.



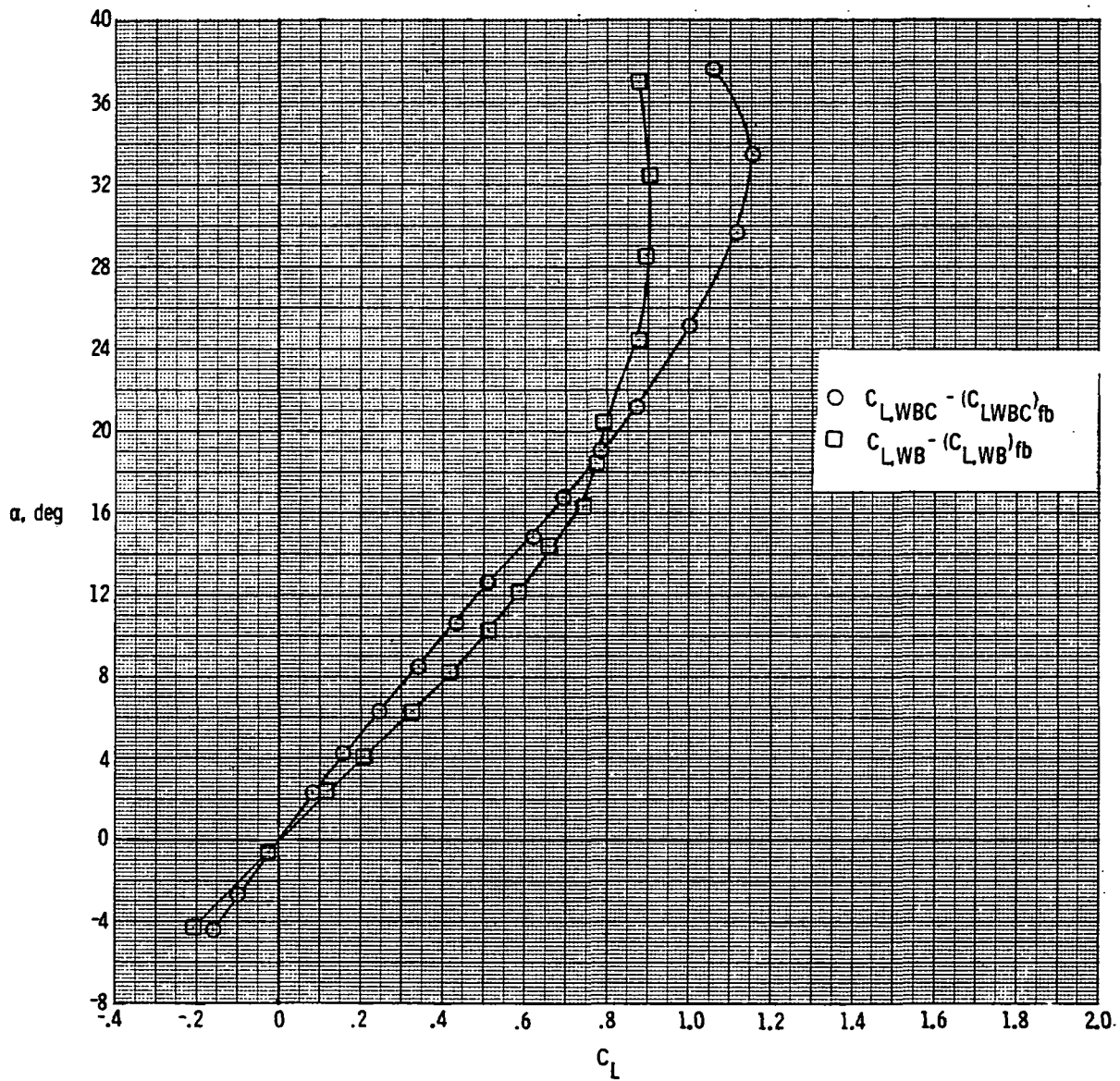
(a) C_m and α plotted against C_L .

Figure 15.- Effect of canard on the longitudinal aerodynamic characteristics of the basic model with vertical tail off.



(b) C_D plotted against C_L .

Figure 15.- Continued.



(c) Interference effects of the canard on wing lift.

Figure 15.- Concluded.

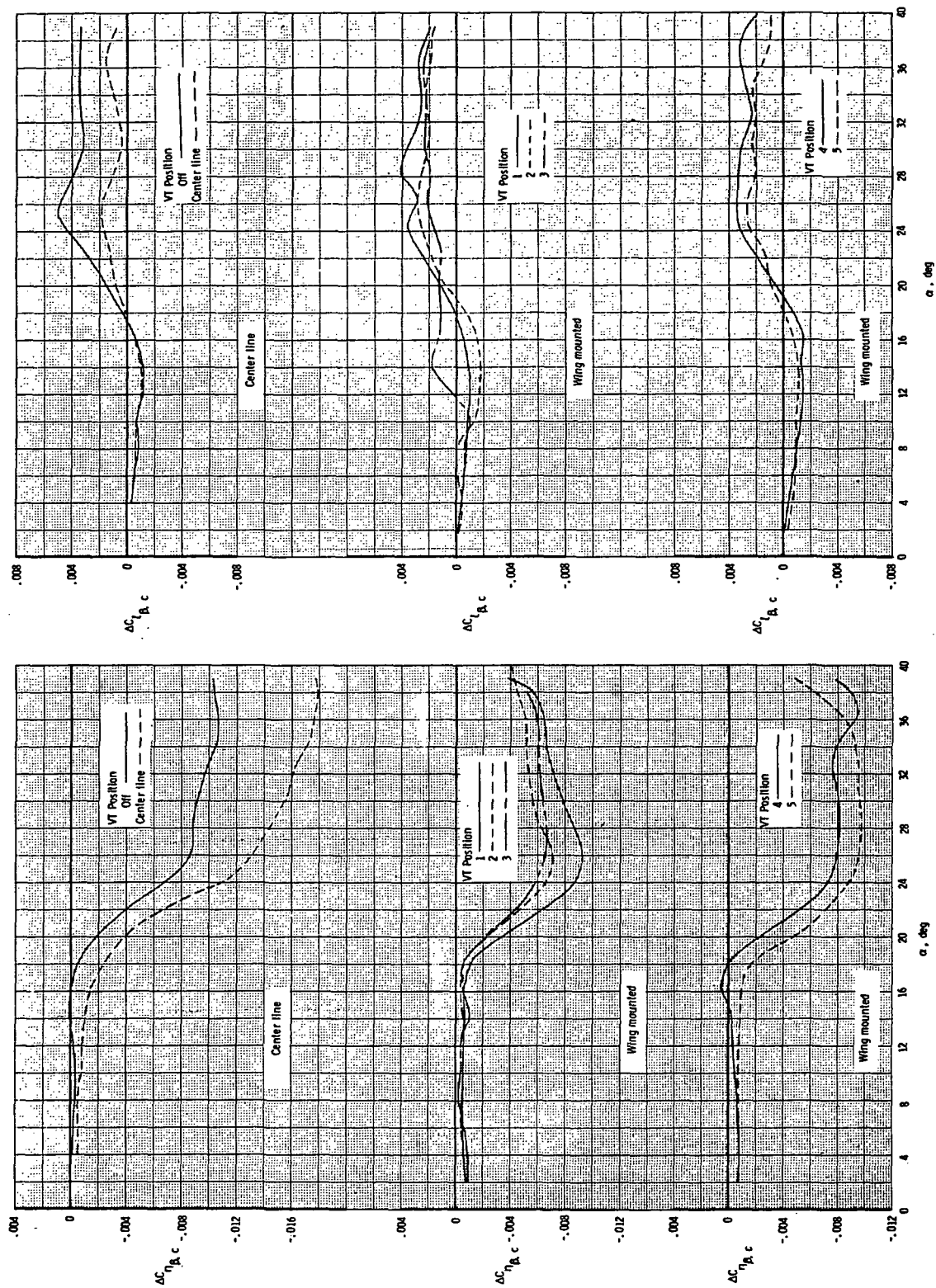
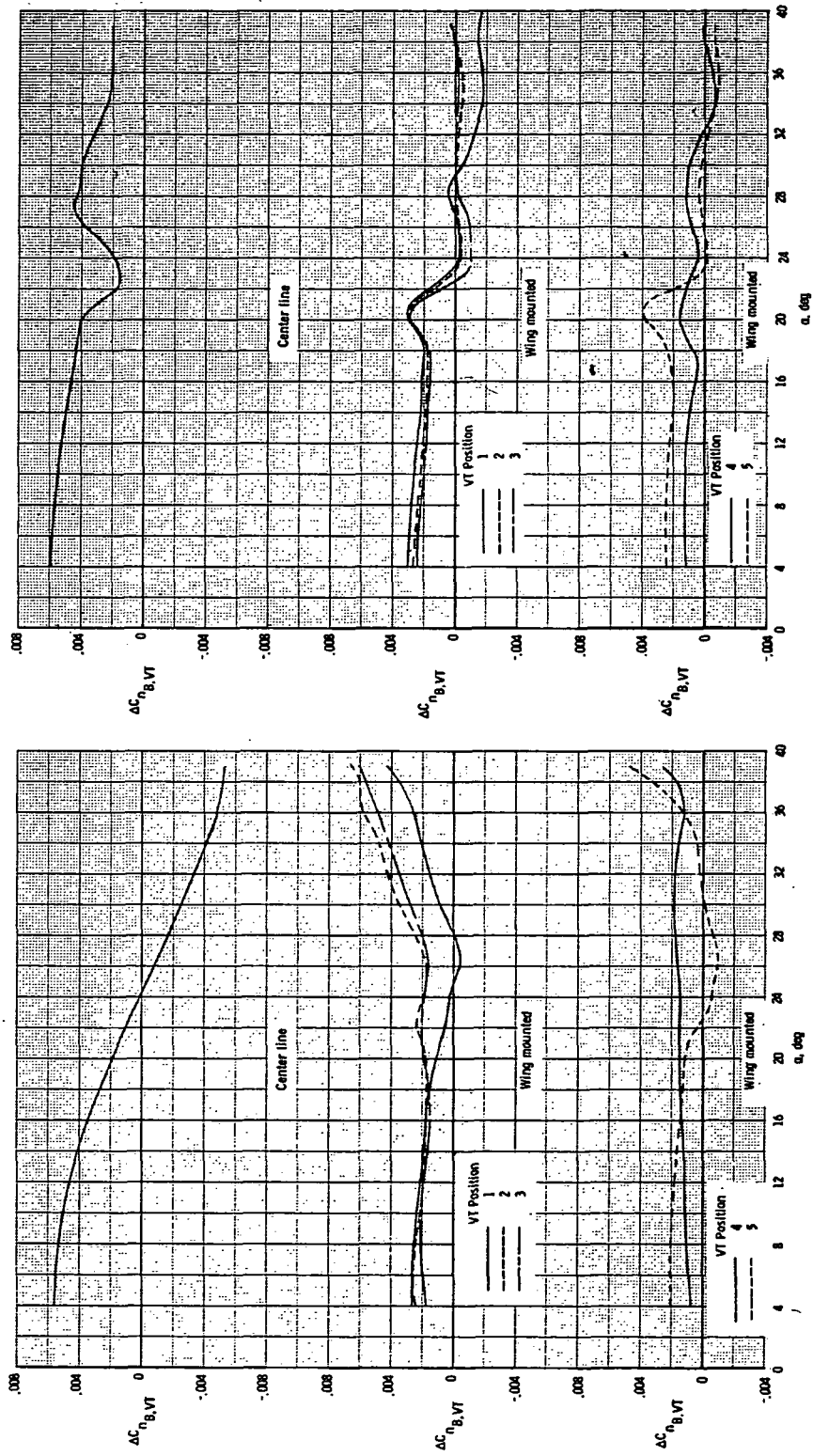


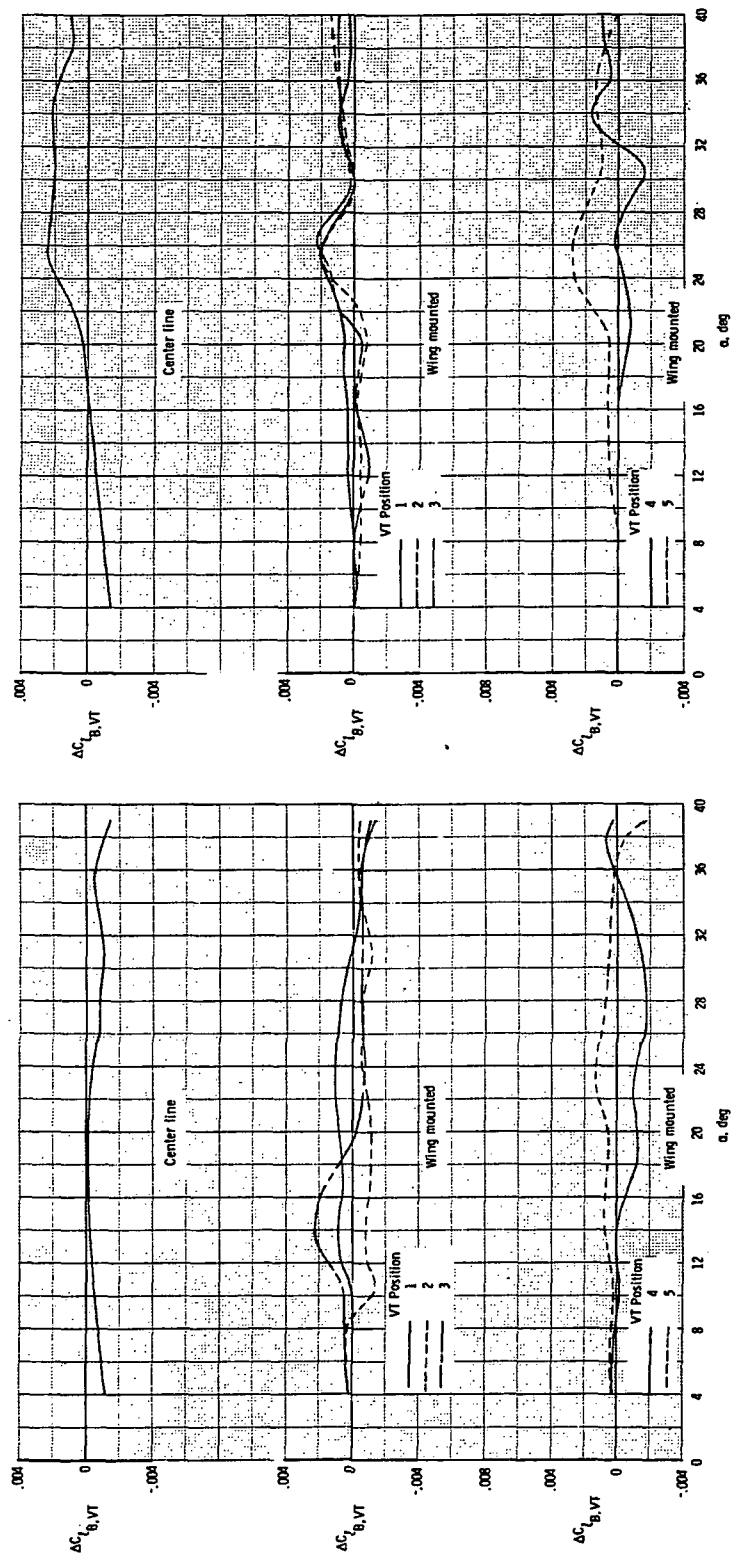
Figure 16.- Interference effects of the canard on lateral-directional derivatives of test models with various vertical-tail configurations.



(a) Canard on.

(b) Canard off.

Figure 17.- Vertical-tail effectiveness for the various vertical-tail configurations.



(a) Canard on.

(b) Canard off.

Figure 18.- Effect of the various vertical-tail configurations on the effective dihedral parameter.

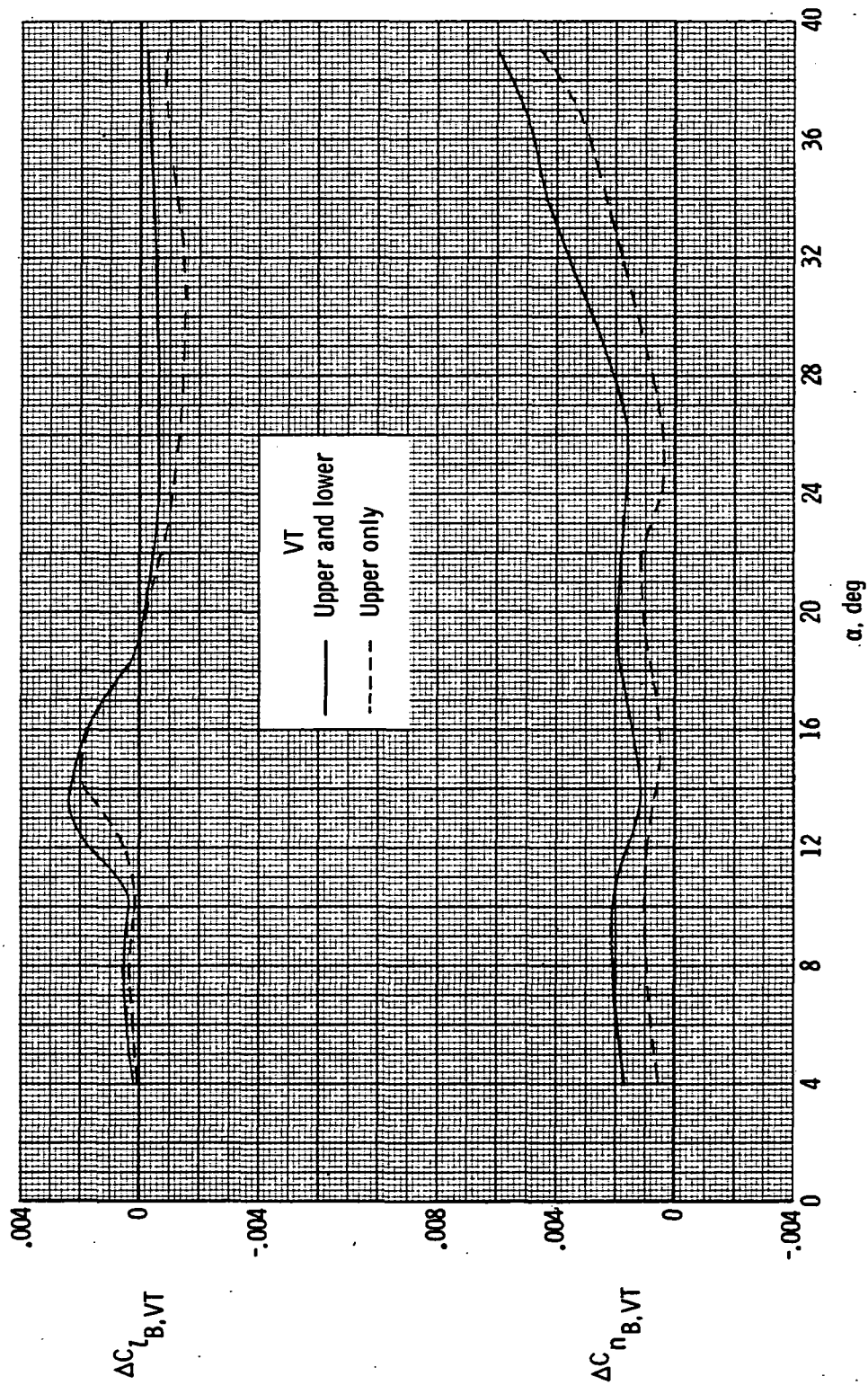


Figure 19.- Vertical-tail effectiveness for the wing-mounted vertical tails at position 3 for the wing-body-canard configuration.